Operating Instructions

GOULD

GOULD BRUSH

MANUAL PART NO.
13-804312-00

D.C. BRIDGE AMPLIFIER
MODEL 13 4312 00

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SECTION I

GENERAL INFORMATION

1.1 INTRODUCTION

Brush D.C. Bridge Amplifier, Model 13-4312-00 is a portable, single channel amplifier for recording from resistive transducers including strain gages and strain gage based transducers. It combines stable d-c excitation, high sensitivity, precision performance--plus unusual convenience of operation.

The amplifier is designed for use with Brush recording systems, and is especially applicable with the portable Brush 220, 260, 280 recorders, and with the high-frequency Lightbeam recorder 2300. It also is applicable in strain measurement systems using other types of display instrumentation.

Transducer excitation is derived from a 5 volt d-c source regulated to ±0.1%. Output is ±2.5 volts full scale into 2K ohm or greater, sufficient for driving Brush pen drive amplifiers, or for other display devices of equal sensitivity. Frequency response is flat to 1 kHz.

Panel controls include an attenuator graduated in five steps from 5% to 100% of transducer load; plus CAL and OFF positions; also locking controls for bridge balance and zero signal positioning, and a ten-turn counting dial which provides simple calibration to known transducer sensitivity or gage factor. A plug-in circuit card has provision for mounting applicable bridge-completion, balance-limiting and calibration resistors. Separate cards are available and may be used in tailoring resistive values to specific transducers or measurements.

FIGURE 1-1 D.C. BRIDGE AMPLIFIER
MODEL 13-4312-00

1.2 SPECIFICATIONS

Signal Source Circuit . . . . . 4 arm resistive bridge

Signal Source Impedance . . . . . 100 ohms to 1,000 ohms

Excitation Source Voltage . . . . . 5 volts d-c ±0.1%

Excitation Source Noise . . . . . 5 mv peak-to-peak, d-c to 1 kHz.

Excitation Source Stability (with respect to)

- Temperature . . . . . ±0.05% per °C
- Time . . . . . ±0.05% per 8 hours (after initial 15 minute warm-up)
- Line . . . . . ±0.1% with 10% line variation

Amplifier Input Circuit . . . . . Balanced to common

Amplifier Input Impedance . . . . . 50K ohms

Amplifier Maximum Sensitivity . . . . . 50 micro inch/inch full scale with 4 active arm bridges having gage factors from 2 to 10

Amplifier Measurement Range . . . . . 500 micro volts full scale to 50 millivolts full scale

Attenuator Inaccuracy . . . . . ±1%

Attenuator Steps . . . . . 5, 10, 20, 50, 100 % LOAD FULL SCALE, OFF and CAL

Signal Output Circuit . . . . . Single-ended, floating or grounded

Signal Output Voltage . . . . . ±2.5 volts into 2K ohm or greater

Signal Output Linearity . . . . . ±0.5% full scale

Signal Output Stability (at 2mV/V Calibration setting and maximum Sensitivity)
(zero with respect to)

- Time . . . . . ±0.5% full scale
- Temperature . . . . . ±0.2% full scale/°C
- Line . . . . . ±0.2% full scale for 10% line change

(gain with respect to)

- Time . . . . . ±0.05%/24 hours after 15 minute warm-up
- Temperature . . . . . ±0.02%/°C
- Line . . . . . ±0.1% for 10% line change

Signal Output Frequency Response . . . . . Flat ±1% to 1 kHz at 2 mV/V calibration setting

Signal Output Noise (at 2 mV/V calibration setting
and maximum sensitivity) . . . . . d-c to 100 Hz, 2% full scale
100 to 1 kHz, 3% full scale

Common Mode Rejection	80 dB at d-c and 60 Hz with 1000 ohm unbalance
Power Requirements	
Voltage	115V/230V ±10%, 50 to 400 Hz
Power	5 watts (6 VA)
Temperature	
Storage	−40°C to +85°C
Operating	0°C to 50°C
Humidity	95% at 32°C

1.3 SUPPLIES AND ACCESSORIES (Items with Asterisks included)

Signal Input Mating Connector*	244811 (Cannon WK-6-21C)
Bridge Completion Plug-in Card*	768735 (includes 15K balance resistor)
Power Input Cable*	247280
Calibration Resistor (15K ohm)*	1-128182-1502 (for 120 ohm bridge)
Calibration Resistor (50K ohm)*	1-128182-5002 (for 350 ohm bridge)
Bridge Completion Resistor (120 ohm)	242879-121
Bridge Completion Resistor (350 ohm)	10-240368-350R0
Six-channel Rack Mounting Adapter	11-1202-10
Filler Panel for Rack Mounting Adapter	
In lieu of One Preamp	269990
In lieu of Two Preamps	266616
Carrying Handle	
For Two Preamps	11-4311-00
For Four Preamps	11-4311-04
For Six Preamps	11-4311-06

SECTION II

INSTALLATION

2.1 GENERAL

This section describes the checks and inspections that should be made upon receipt of Brush Portable D.C. Bridge Amplifier, typical signal input and output connections, rack mounting installation, and outline dimensions.

2.2 INITIAL INSPECTION

Before attempting any electrical connections or operation, visually examine unit for shipping damage, broken or loose knobs, broken or chipped rear connectors, and dented or nicked panels.

2.3 INSTALLATION

The D.C. Bridge Amplifier is a completely portable unit and requires only a power source of 115/230 volts, 50-400 Hz for proper operation.

2.4 SIGNAL CABLE CONNECTIONS

1. Use a four conductor, double foil, shielded signal cable, Belden No. 8434, Brush part number 232956, or equivalent. The cable run from transducer to preamplifier should be one continuous length. No splices are permitted, but mating low level signal connectors may be used if necessary.

2. Connect the double shielded signal cable pair to preamplifier signal input connector, pins 2 and 3.

3. Connect the shielded signal cable pair to transducer excitation plus 1 and 4 as shown in Figure 2-1.

4. Connect the signal cable shield to signal input connector. Ground the signal cable shield at the transducer.

NOTE: Detailed instructions for connecting one, two, or four arm gages is given in Section III, Operation.

2.5 PREAMPLIFIER POLARITY

1. When a positive signal is applied to a transducer we would expect the pen on the recorder chart to move from chart center (up scale) to the left.

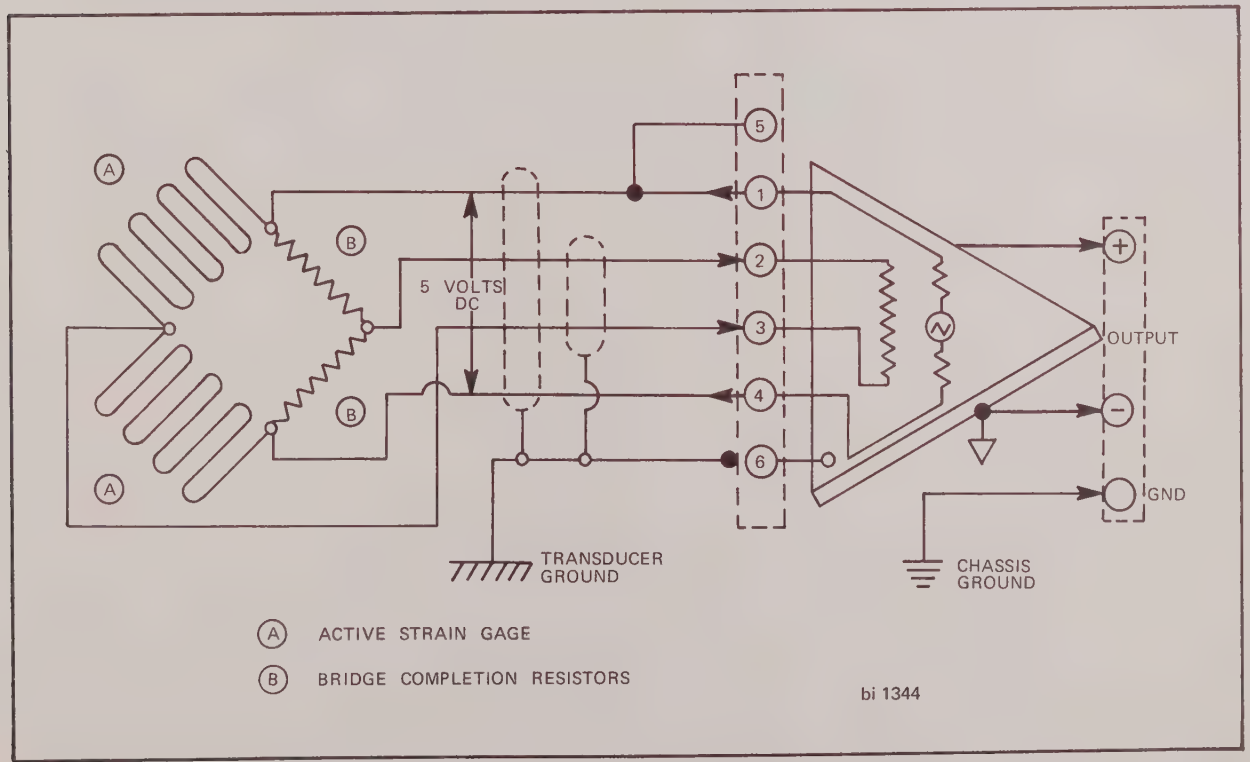


FIGURE 2-1 TYPICAL SIGNAL CONNECTIONS

2. When connecting the D.C.Bridge Amplifier to recorder, connect the output so that a clockwise rotation of the POSITION knob moves the pen to the right.

2.6 OUTPUT CONNECTIONS

Signal output connections to D.C. Bridge Amplifier can be easily made using a two conductor cable terminated on one end with either a GR connector (Brush part number 103503) for use with Brush 220 and 280, or with an Amphenol connector (Brush part number 234321) for use with Brush 260 and 2300 Lightbeam. Be sure to wire connectors according to installation instructions given in the particular recorder manual.

NOTE: Under normal operating conditions, ground strap on D.C. Bridge Amplifier should be disconnected from the signal output LO terminal, if a single ended grounded readout is to be used.

1. When connecting to a Brush 220 recorder, it is important that signal HI on amplifier connects to input terminal 1, and signal LOW on amplifier connects to input terminal 2. Ground strap on Brush 220 may be left on or off, but best results will be obtained with ground strap connected to terminal 2.

2. When connecting to a Brush 260 it is important that signal HI on amplifier connects to pin 1 of input connector, signal LO connects to pin 2 and shield connects to pin 3.

2.7 RACK MOUNTING INSTALLATION

Brush D.C. Amplifier, Model 13-4312-00 may be conveniently rack mounted in a Brush Rack Mounting Adapter, Model 11-1202-10. Each adapter mounts six 13-4312 series amplifiers and installs in any standard 19 inch RETMA cabinet.

To install the Rack Mounting Adapter, refer to Figure 2-2 and proceed as follows:

1. Assemble items 1, 4 and 5 to cabinet rails using item 9.

2. Assemble item 3 using items 6, 7, and 8.

3. Remove four rubber feet from bottom of amplifier.

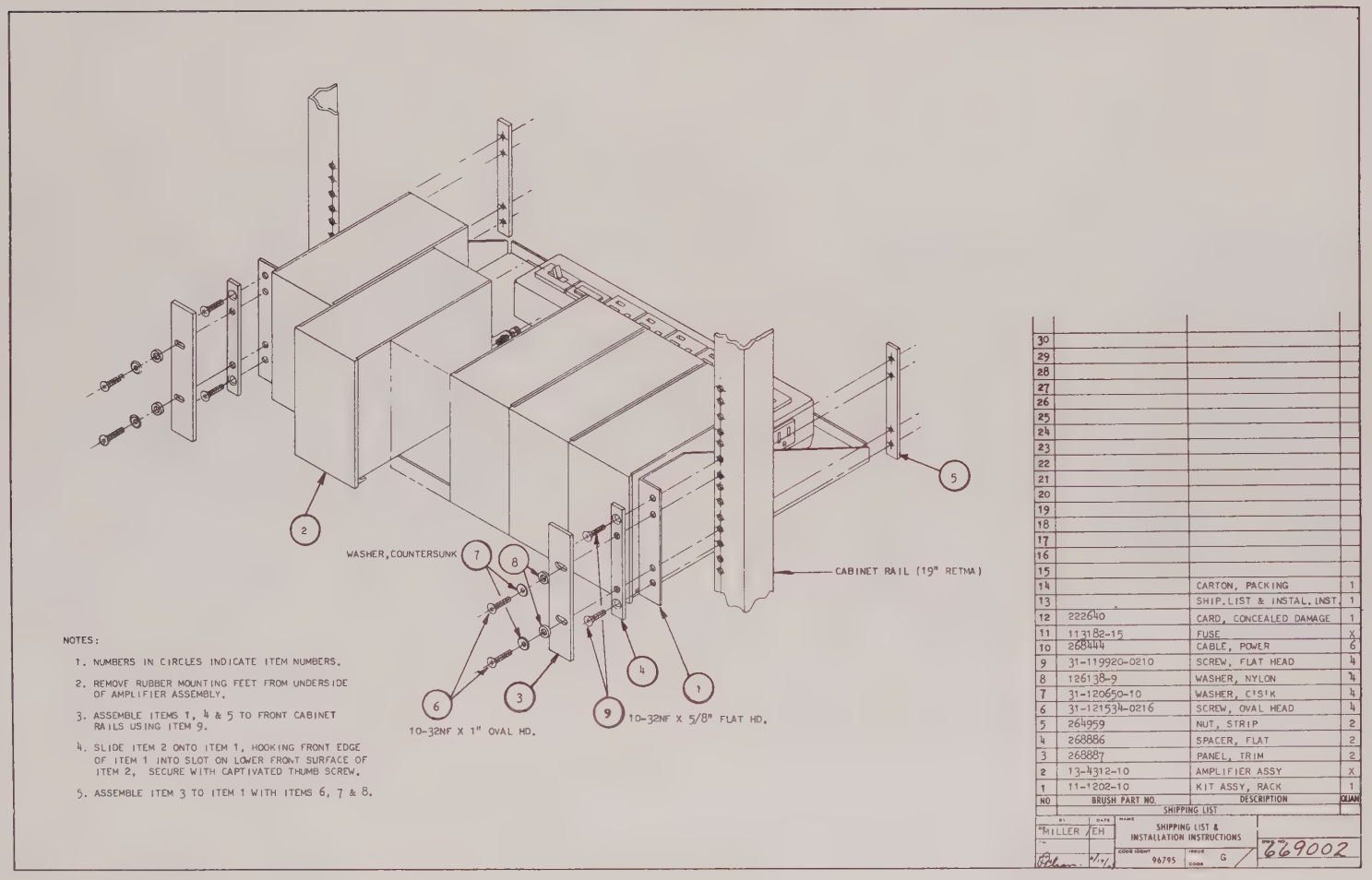
4. Slide amplifier onto mounting rack, hooking front edge of rack into slot on lower front surface of amplifier.

5. From rear of cabinet, secure amplifier with captivated thumb screw.

6. Make all power and signal input and output connections. Power cords may be connected to plug-in box located on rear of mounting rack.

2.8 OUTLINE DIMENSIONS

Preamplifier outline dimensions are shown in Figure 2-3.



NOTES:

1. NUMBERS IN CIRCLES INDICATE ITEM NUMBERS.
2. REMOVE RUBBER MOUNTING FEET FROM UNDERSIDE OF AMPLIFIER ASSEMBLY.
3. ASSEMBLE ITEMS 1, 4 & 5 TO FRONT CABINET RAILS USING ITEM 9.
4. SLIDE ITEM 2 ONTO ITEM 1, HOOKING FRONT EDGE OF ITEM 1 INTO SLOT ON LOWER FRONT SURFACE OF ITEM 2. SECURE WITH CAPTIVATED THUMB SCREW.
5. ASSEMBLE ITEM 3 TO ITEM 1 WITH ITEMS 6, 7 & 8.

NO	BRUSH PART NO.	DESCRIPTION	QUAN
30			
29			
28			
27			
26			
25			
24			
23			
22			
21			
20			
19			
18			
17			
16			
15			
14		CARTON, PACKING	1
13		SHIP. LIST & INSTAL. INST.	1
12	222640	CARD, CONCEALED DAMAGE	1
11	113182-15	FUSE	X
10	268444	CABLE, POWER	6
9	31-119920-0210	SCREW, FLAT HEAD	4
8	126138-9	WASHER, NYLON	4
7	31-120650-10	WASHER, C'SK	4
6	31-121534-0216	SCREW, OVAL HEAD	4
5	264959	NUT, STRIP	2
4	268886	SPACER, FLAT	2
3	268887	PANEL, TRIM	2
2	13-4312-10	AMPLIFIER ASSY	X
1	11-1202-10	KIT ASSY, RACK	1

SHIPPING LIST

BY	DATE	NAME
MILLER	7/1/	EH

SHIPPING LIST & INSTALLATION INSTRUCTIONS

CODE IDENT 96795 ISSUE CODE G

669002

FIGURE 2-2 RACK MOUNTING ADAPTER

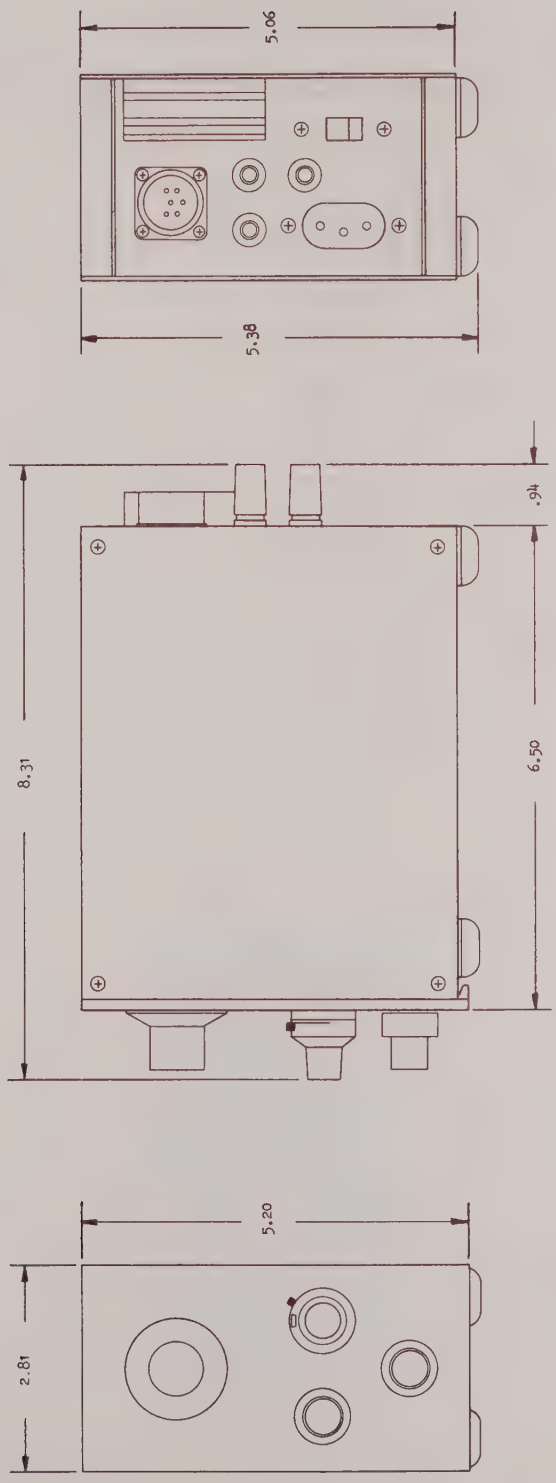


FIGURE 2-3 DIMENSIONAL OUTLINE

SECTION III

OPERATION

3.1 GENERAL

This section describes and illustrates the controls on D.C. Bridge Amplifier and provides instructions for proper operation.

3.2 CONTROL DESCRIPTION

NOTE: Item numbers listed below correspond to circled numbers in Figure 3-1.

1 SENSITIVITY . . . . . A seven-position rotary switch permits selection of 5, 10, 20, 50 and 100% of load for full scale, OFF and CAL.

NOTE: OFF position does not remove primary power or strain gage excitation.

NOTE: To convert readings to microinch/inch, full scale, multiply %—of—load setting by 10.

2 BALANCE . . . . . Multi-turn control permits balancing out static errors with no load on strain gage. This control is fitted with a locking knob to prevent inadvertent turning.

3 CALIBRATE . . . . . Ten-turn counting dial that provides fast, convenient calibration of unit. Strain gage sensitivity in millivolts per volt full scale output can be directly dialed in to calibrate system.

NOTE: Calibrate dial is preset at factory and will not go to zero (0.0).

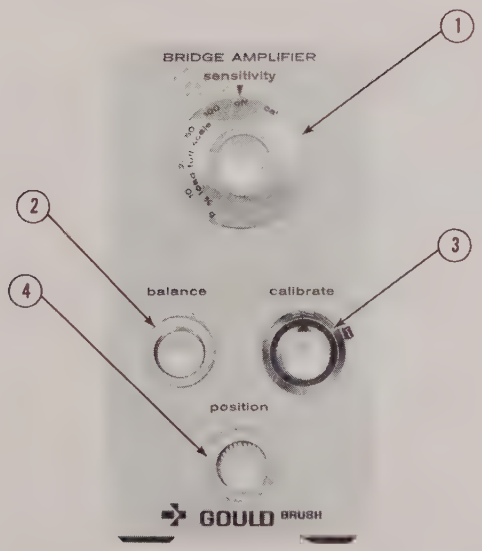


FIGURE 3-1 FRONT PANEL CONTROLS

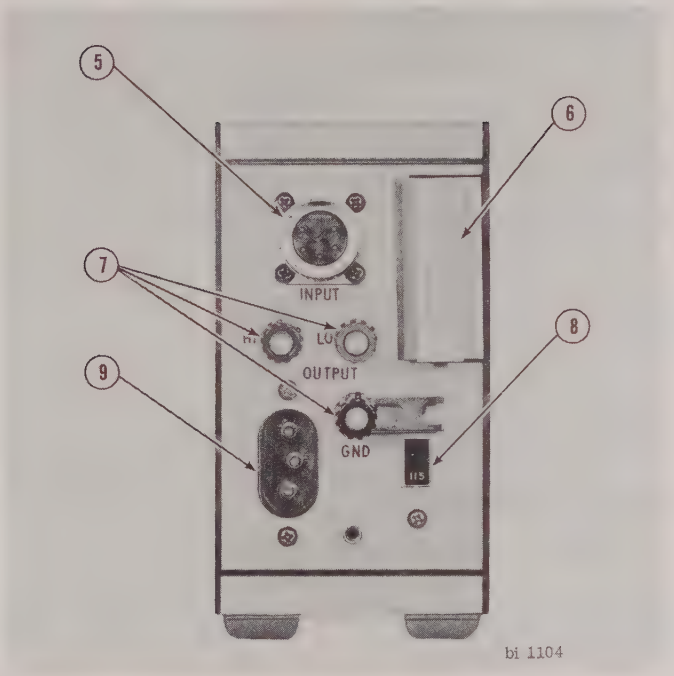


FIGURE 3-2 REAR PANEL

4 POSITION	Permits zero positioning signal anywhere on display, ±2.8 volts, minimum. This control is fitted with a locking knob to prevent inadvertent turning.

NOTE: Item numbers listed below correspond to circled numbers in Figure 3-2.

5 Input Connector	Six pin connector. Provides d-c excitation output and strain gage inputs to unit.
6 Bridge Completion Board	Provides for convenient mounting of bridge completion resistors when using one or two arm gages. Also provides terminals for balance resistor and optional calibration resistor.
7 Output Terminals	G-R connectors. Low side of floating output may be grounded with removable ground strap.
8 115/230 Volt Switch	Enables either 115 volt or 230 volt operation.
9 Power Input Connector	3 pin grounded connector.

3.3 OPERATION WITH BRUSH RECORDERS

a. Direct Writing Recorders

NOTE: When using this amplifier in conjunction with a recorder which contains its own built-in preamplifier, pen position control, attenuator (SENSITIVITY) control, such as on a Brush 220 or 260, it is important that controls be pre-set and controls on amplifier be used. To correctly set controls for proper operation, proceed as follows:

1. Set recorder SENSITIVITY to OFF position.
2. Adjust recorder PEN POSITION to exact chart center and lock knob.
3. Check that recorder vernier SENSITIVITY X1 control is in detent position, and lock knob.
4. Set recorder SENSITIVITY to 100 millivolts per division.
5. Proceed with amplifier operation, Para. 3.5.

b. Light Beam Oscillograph

When using the D.C. Bridge Amplifier with the Brush 2300 Light Beam Oscillograph, it is necessary to adjust any intermediate signal conditioning equipment so that only the controls on the D.C. Bridge Amplifier affect galvo spot position.

All information regarding galvo drive amplifiers, matching networks, etc., can be found in the Light Beam Oscillograph manual.

3.4 INPUT CONNECTIONS TO BRIDGE AMPLIFIER

Input connections for resistance strain gages to the D.C. Bridge Amplifier vary slightly because of the number of active arms in the strain gage.

NOTE: Use cable, Brush part number 232956 (Belden 8434) or equivalent.

a. Connecting a Four-Arm Gage

NOTE: Refer to Figure 3-3.

1. Be sure to make all gage connections to the amplifier using the mating connector supplied (Brush part number 244811).
2. Place a jumper wire from pin 5 to pin 1.

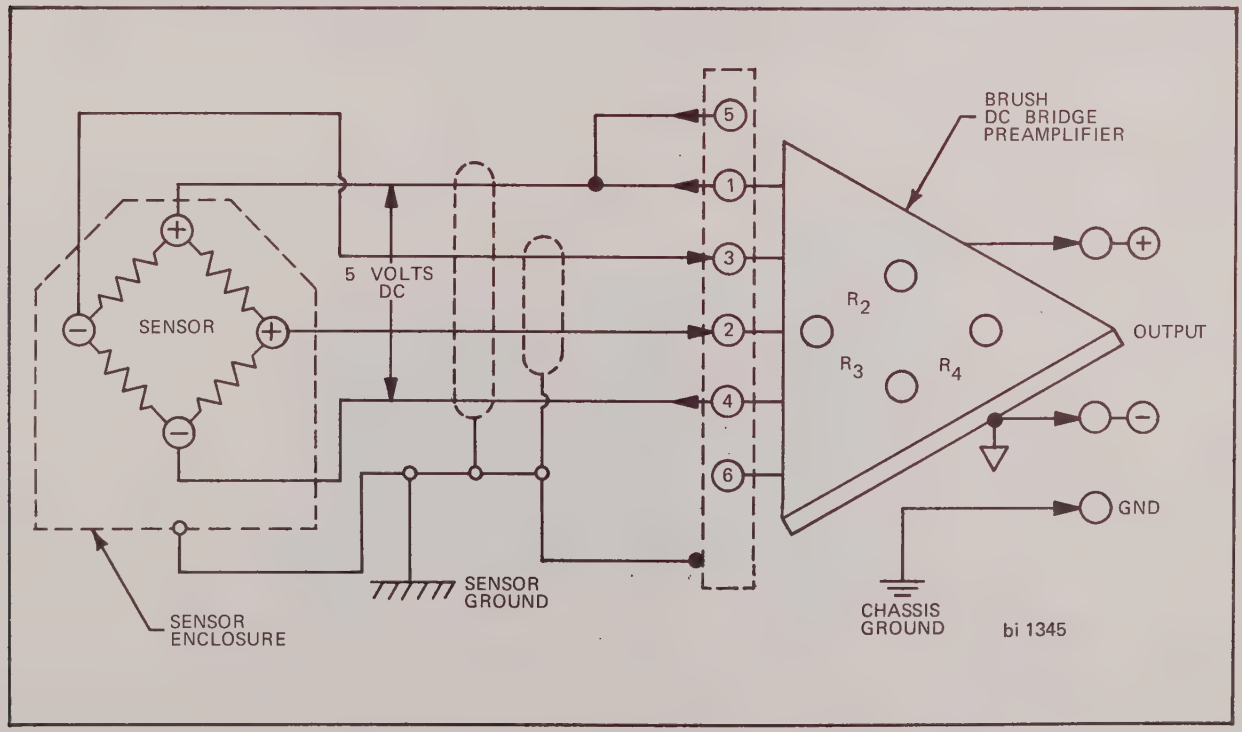


FIGURE 3-3 CONNECTING FULL-BRIDGE SENSORS

3. Connect excitation leads to pins 1 (positive) and 4 (negative).

4. Connect signal leads to pins 2 (positive) and 3 (negative).

5. Connect cable shield to input connector shell.

6. A jumper wire on pin 6 will determine polarity of a calibration signal. Placing a jumper from pin 6 to pin 2 will give a positive deflection; a jumper from pin 6 to pin 3 will give a negative deflection.

NOTE: To use the CAL feature of this unit, a calibration resistor must be installed on the Bridge completion board. A 15K ohm resistor is used for 120 ohm gage, and 50K ohm is used for 350 ohm gage. Refer to Figure 3-4.

7. Check to be sure balance resistor is installed.

8. After connecting gage to amplifier, proceed with Para. 3.5.

b. Connecting a Two-Arm Gage

NOTE: Refer to Figure 3-5.

1. Use a good strain gage cable, Brush part number 232956 (Belden 8434).

2. Be sure to make all gage connections to the amplifier using the mating connector supplies (Brush part number 244811).

3. Place a jumper wire from pin 5 to pin 1.

4. Connect excitation lead to pin 1 (positive).

5. Connect signal leads to pins 2 (positive) and 3 (negative).

6. Connect cable shield to input connector shell.

7. A jumper wire from pin 6 to pin 2 will provide positive calibration. A jumper wire from pin 6 to pin 3 will provide negative calibration.

NOTE: To use the CAL feature of this unit, a calibration resistor must be installed on the Bridge completion board. A 15K ohm resistor is used for 120 ohm gage and 50K ohm is used for 350 ohm gage. (Refer to Figure 3-4)

8. Check to be sure balance resistor is properly installed.

9. On Bridge completion board, install two bridge completion resistors for R-3 and R-4.

10. Resistors must be precision, wire-wound and

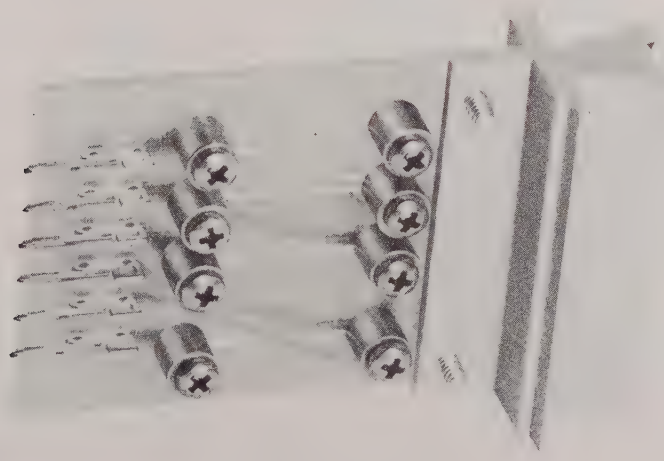


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FIGURE 3-4 BRIDGE COMPLETION BOARD

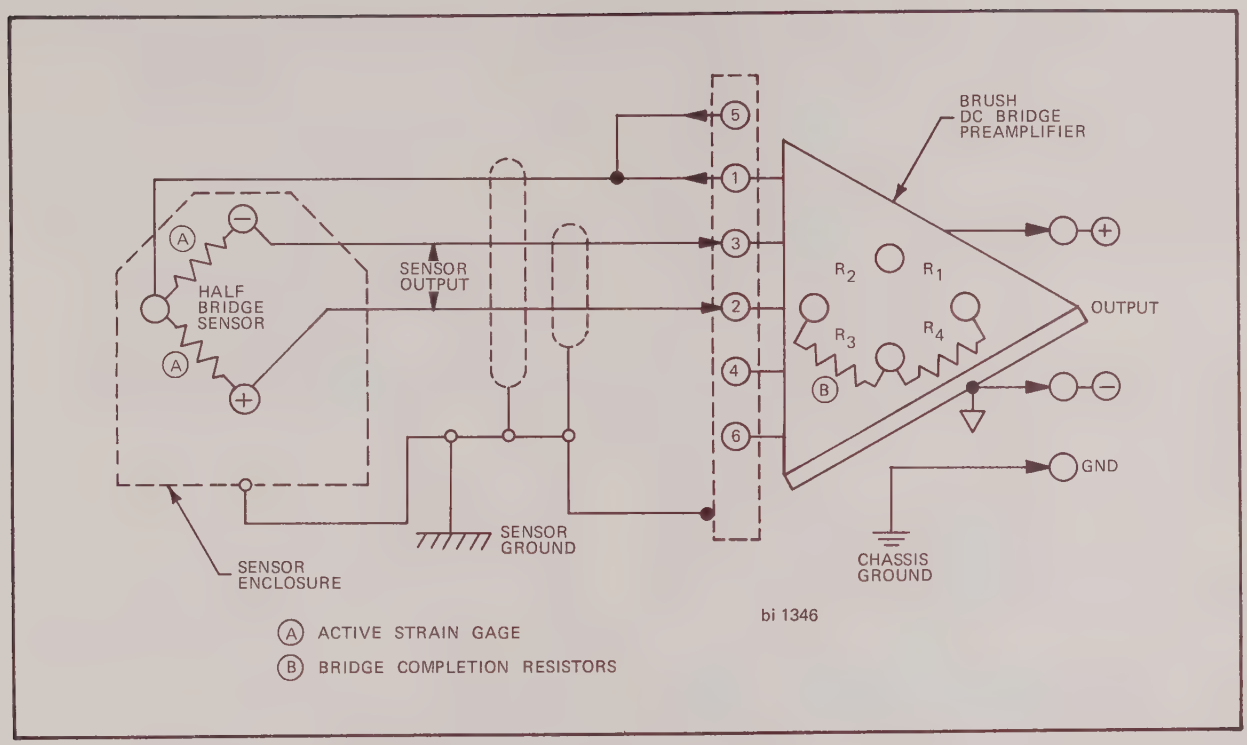


FIGURE 3-5 TWO ARM GAGE CONNECTIONS

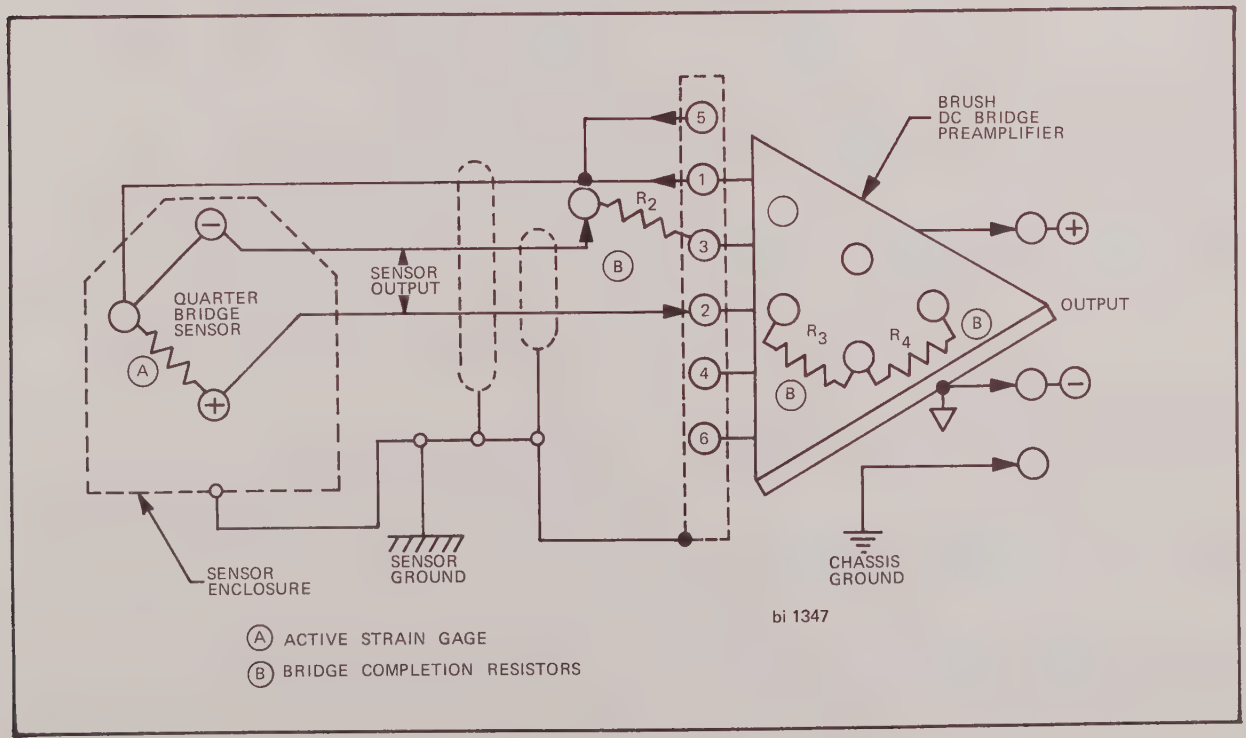


FIGURE 3-6 SINGLE ARM GAGE CONNECTIONS

of the exact resistance values as the two active arms of the gage.

11. Now proceed with Para. 3.5.

c. Connecting a Single-Arm Gage

NOTE: Refer to Figure 3-6.

1. Use a good strain gage cable, Brush part number 232956, (Belden 8434).

2. Be sure to make all gage connections to the amplifier using the mating connector supplies (Brush part number 244811).

3. Install a jumper wire from pin 5 to pin 1.

4. Connect excitation lead to pin 1 (positive).

5. Connect signal lead to pin 2 (positive).

NOTE: Be sure to use lead from active arm of gage as shown in Figure 3-6.

6. Connect cable shield to input connector shell.

7. To provide temperature compensation, connect Bridge completion resistor R-2 to input pin 3. (Resistor mounts inside input connector shell.) Connect remaining signal lead from strain gage to free end of resistor.

8. Mount remaining two resistors on Bridge completion board assembly.

NOTE: Completion resistors must be precision, wire-wound, and of the exact resistance value as the active arm of the gage.

9. A jumper wire from pin 6 to pin 2 will provide positive calibration. A jumper wire from pin 6 to pin 3 will provide negative calibration.

NOTE: To use the CAL feature of this unit, a calibration resistor must be installed on the Bridge completion board. A 15K ohm resistor is used for 120 ohm gage and 50K ohm is used for 350 ohm gage. (Refer to Figure 3-4)

10. Check to be sure balance resistor is properly installed.

11. Now proceed with Para. 3.5.

3.5 OPERATING THE D.C. BRIDGE AMPLIFIER

Operation of the D.C. Bridge Amplifier has slight variations because of the number of active arms in the strain gage.

NOTE: When using the D.C. Bridge Amplifier in conjunction with Brush recorders, operate the chart at moderate speed during set up and calibration of system.

a. Operation with a Four-Arm Gage

1. Set gage sensitivity (gage factor) on CALIBRATE dial.

NOTE: Setting on CALIBRATE dial must never be less than 1.00.

2. Set amplifier SENSITIVITY to OFF.

3. Use amplifier POSITION control to set signal (pen or galvo spot) to chart center.

NOTE: Although the full scale capabilities of the amplifier can only be achieved if a chart edge is used for "zero" load position, chart center should be used for greater ease in balancing the amplifier.

4. Check to be sure gage is in "no load" condition.

5. Rotate SENSITIVITY to 100% position.

6. Use BALANCE control to return signal to "zero" position established in step 3.

7. Continue to rotate SENSITIVITY control clockwise and use BALANCE control to keep signal at "zero" position until amplifier is balanced at 5% setting.

8. Return SENSITIVITY to OFF.

9. Amplifier is now properly balanced. To obtain full scale readings, use POSITION control to set "zero" position to the chart edge.

10. If gage sensitivity (gage factor) is unknown, but calibration resistance is given, then proceed with items 11 thru 12.

11. Since gage sensitivity (gage factor) is unknown, set CALIBRATE dial to 2.00, and balance amplifier as in steps 2 thru 9.

12. Rotate SENSITIVITY to CAL position. Adjust CALIBRATE dial to cause pen to equal the proper deflection as indicated by the gage manufacturer. Record calibrate setting and retain for future use with specific gage.

13. A gage can also be calibrated by applying a full load condition to the gage and adjusting the CALIBRATE dial for full scale (edge-to-edge) pen deflection. This should be accomplished with the SENSITIVITY set on 100%.

NOTE: Setting on the CALIBRATE dial must never be less than 1.00.

b. Operation with a Two-Arm Gage

1. Operation is identical to operation with four-arm gage with the following exceptions due to the sensitivity of the two-arm gage being half of the four-arm gage.

2. All SENSITIVITY control settings must be multiplied by two to get actual strain readings for a two-arm gage, if gage factor is dialed in directly.

3. Change step a, 13 to read: A two-arm gage can also be calibrated by applying a full load condition to the gage and adjusting the CALIBRATE dial for full scale (edge-to-edge) pen deflection, with SENSITIVITY set on 50%.

NOTE: The setting on the CALIBRATE dial must never be less than 1.00. Therefore, if gage factor is greater than 2.0 then CALIBRATE dial can be set to one-half the gage factor and sensitivity can be used directly as in the four-arm gage procedure.

c. Operation with a One-Arm Gage

1. Due to the sensitivity of the one-arm gage being one fourth that of the four-arm gage, operation is identical to operation with a four-arm gage with the following exceptions:

2. All SENSITIVITY control settings must be multiplied by four to get actual strain readings for a one-arm gage, if gage factor is dialed in directly.

3. Change step a,13 to read: A one-arm gage can also be calibrated by applying a full load condition to the gage and adjusting the CALIBRATE dial for chart center-to-edge pen deflection, with SENSITIVITY set on 50%.

NOTE: The setting on the CALIBRATE dial must never be less than 1.00. Therefore, if gage factor is greater than 4.0, then CALIBRATE dial can be set to one-fourth the gage factor and sensitivity can be used directly as in the four-arm gage procedure.

3.6 OPERATION AS A D.C. AMPLIFIER

The Brush D.C. Bridge Amplifier can be satisfactorily used as a sensitive D.C. Amplifier. with a gage factor setting of 2.00, input sensitivities range from 10 microvolts per division to 10 millivolts full scale. The following list indicates SENSITIVITY control settings and corresponding voltage sensitivities:

Sensitivity % F.S.	Volts Full Scale	Volts Per Division
100	10 millivolts	200 microvolts
50	5 millivolts	100 microvolts
20	2 millivolts	40 microvolts
10	1 millivolts	20 microvolts
5	0.5 millivolts	10 microvolts

To use the D.C. Bridge Amplifier simply connect input signals to pin 2, High, pin 3, Low, and connector shell, shield.

3.7 CALCULATING CALIBRATION RESISTANCE AND CALIBRATION DEFLECTION

Formula for calculating calibration resistor or calibration deflection with known calibration resistor is:

$$\text{Simulated Calibration Load} = \frac{(\Delta L)}{(L)} = \frac{R}{G_f N R_c}$$

where:

R = Resistance value of each active gage.

G_f = Gage factor for each active gage, or voltage sensitivity of transducer

N = Number of active gages

R_c = Resistance value of calibration resistor.

Typical Example: Strain gage bridge with four active arms each 120 ohms. Gage factor 2.00 with 15K calibration resistor

$$\frac{\Delta L}{L} = \frac{120}{(2.00)\,(4)\,(15{,}000)}$$

$$= \frac{120}{0.120 \times 10^{+6}}$$

$$= 1000 \times 10^{-6}$$

= 1000 microstrain

= 100% full scale

= 50 divisions calibration deflection

General formula for CAL deflection for 120 ohm bridge with four active arms, using 15K calibration resistor.

$$(\%\ \text{Full Scale}) = \frac{200.0}{\text{gage factor}}$$

3.8 OPERATION WITH TRANSDUCERS HAVING INTERNAL SHUNT CALIBRATION RESISTOR

Transducers which contain a built-in shunt resistor to give a "% of full scale" calibration signal can easily be used with the D.C. Bridge Amplifier. Refer to transducer manufacturer's instructions for electrical connections to the transducer.

Transducers of this type fall into two major types: A) those with the calibration resistor connected to the negative excitation terminal of the bridge and, B) those with the calibration resistor connected to the negative output terminal of the bridge.

If the transducer is type A, to obtain positive calibration, place a jumper between terminals 3 and 7 (Figure 3-7). To obtain negative calibration, place a jumper between terminals 1 and 7.

If the transducer is type B, to obtain positive calibration, place a jumper between terminals 7 and 8. To obtain negative calibration, place a jumper between terminals 4 and 7.

In each case, input connector pin 6 must be connected to the internal calibration resistor. The extra input lead required must be an integral part of the input cable. Refer to Paragraph 6.10, Temperature Compensation.

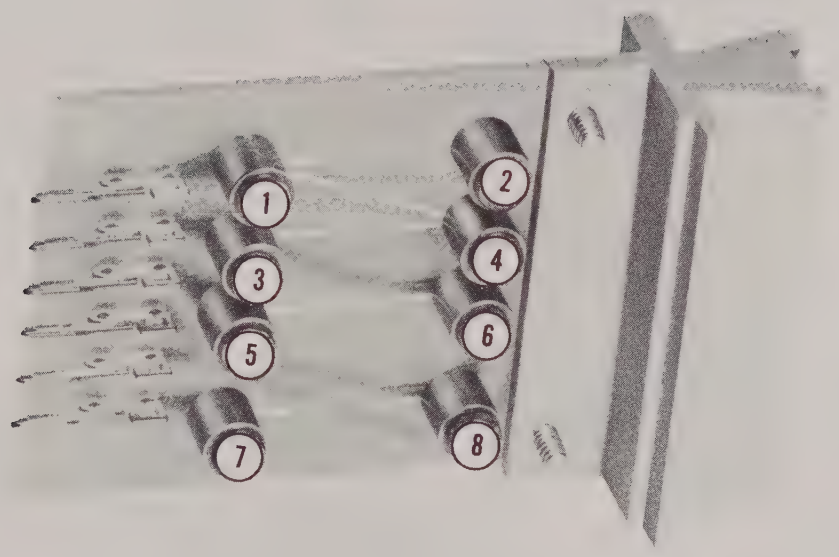


FIGURE 3-7 BRIDGE COMPLETION CARD

SECTION IV

THEORY OF OPERATION

4.1 GENERAL

The D.C. Bridge Amplifier, Model 13-4312-00 consists of a balanced differential input section, a stepped attenuator, an output amplifier, and a regulated d-c power supply which provides excitation to strain gage and operating voltage to amplifiers (Fig. 4-1 and schematic 268783).

4.2 INPUT AMPLIFIER

The output from strain gage is applied directly to input resistors R-201 and R-204, then to dual transistor Q-201A and Q-201B. Variable resistor, R-202 provides common mode rejection balance adjustment. Variable resistor R-208 provides a balancing adjustment of the output of Q-201A and Q-201B, which is applied to an integrated circuit, IC-201. The output of IC-201 is connected directly to attenuator, S-301 and to calibration control, R-302. Output of calibration control varies amplifier gain from 50 to 250.

4.3 ATTENUATOR

Output of IC-2-1 is connected directly across five resistors, R-304 thru R-308 to common. Calibrate position places a calibrate resistor in parallel with one arm of strain bridge. Output from attenuator S-301, is connected directly to output amplifier, IC-202.

4.4 OUTPUT AMPLIFIER

Input to IC-202 is summed with a pen position signal derived from variable resistor, R-301. Output of IC-202 is taken across resistor, R-215.

4.5 D.C. POWER SUPPLY

Power supply is operated directly off 115/230 volt, 50-400 Hz line. One secondary of transformer T-101 is connected to diodes, CR-101 and CR-102 and capacitor C-101 which form a full wave rectifier. Transistor, Q-101 in conjunction with integrated circuit, IC-101 provide a stable regulated d-c excitation voltage to strain gage and to balance control R-301. This d-c voltage is set to 5 volts by variable resistor, R-103. The other secondary of transformer T-101 is full wave rectified and filtered by diode bridge CR-103 and capacitors C-103 and C-105. Transistors Q-102 and Q-103 produce a regulated plus and minus 14.4 volts for operating amplifier circuitry. Zener diodes, CR-107 and CR-108 and resistors R-109 and R-110 provide plus and minus 3.3 volts for POSITION control, R-303.

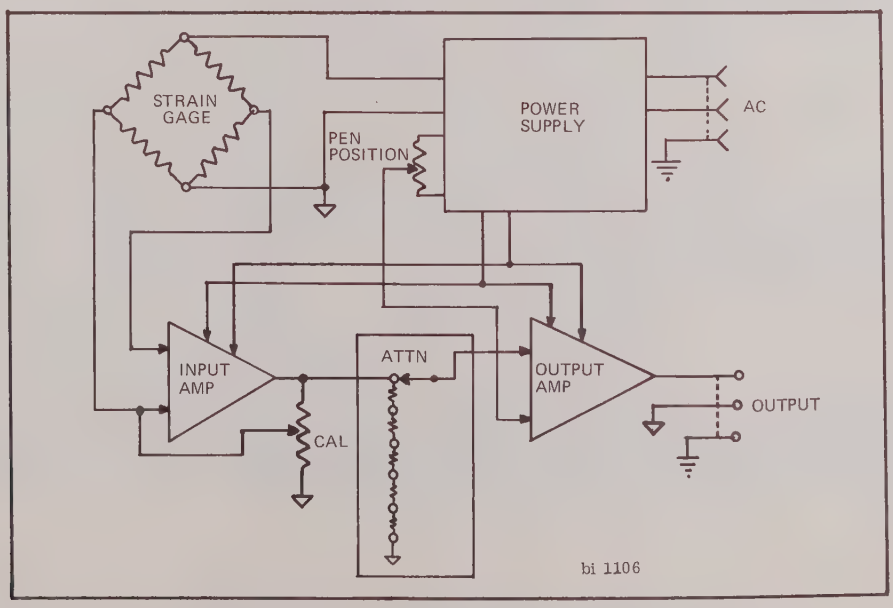


FIGURE 4-1 THEORY OF OPERATION - BLOCK DIAGRAM

SECTION V

CALIBRATION

5.1 GENERAL

Brush D.C. Bridge Amplifier, Model 13-4312-00 is built to the highest precision standards featuring maximum operational efficiency and dependability. It has been accurately calibrated and adjusted before shipment from factory, and should give long, trouble-free service. Normal aging and/or replacement of parts may require calibration.

5.2 TEST EQUIPMENT REQUIRED

The following is a list of test equipment necessary for calibration:

NOTE: Specific manufacturer need not be adhered to, but comparable equipment is mandatory, since accuracy stated is imperative.

1. General Purpose VOM (Triplett Model 630 or equivalent).
2. AC-DC Differential Voltmeter (John Fluke Model 803B or equivalent).
3. Oscilloscope with adjustable filter (Tektronix Model 531 with Model 1A7 plus-in unit or equivalent).
4. Signal Generator (Wavetek Model 110 or equivalent).

5.3 PROCEDURE

1. Be sure to remove input signal connector, output connector, and disconnect primary input power.
2. Remove right side cover by removing four flat-head screws.
3. Remove amplifier circuit board by removing five circuit board fasteners. This can be done easily with a pair of common pliers.
4. Lay circuit board over as shown in Figure 5-1.
5. Connect unit to power source (check for proper position of rear panel voltage selector switch).

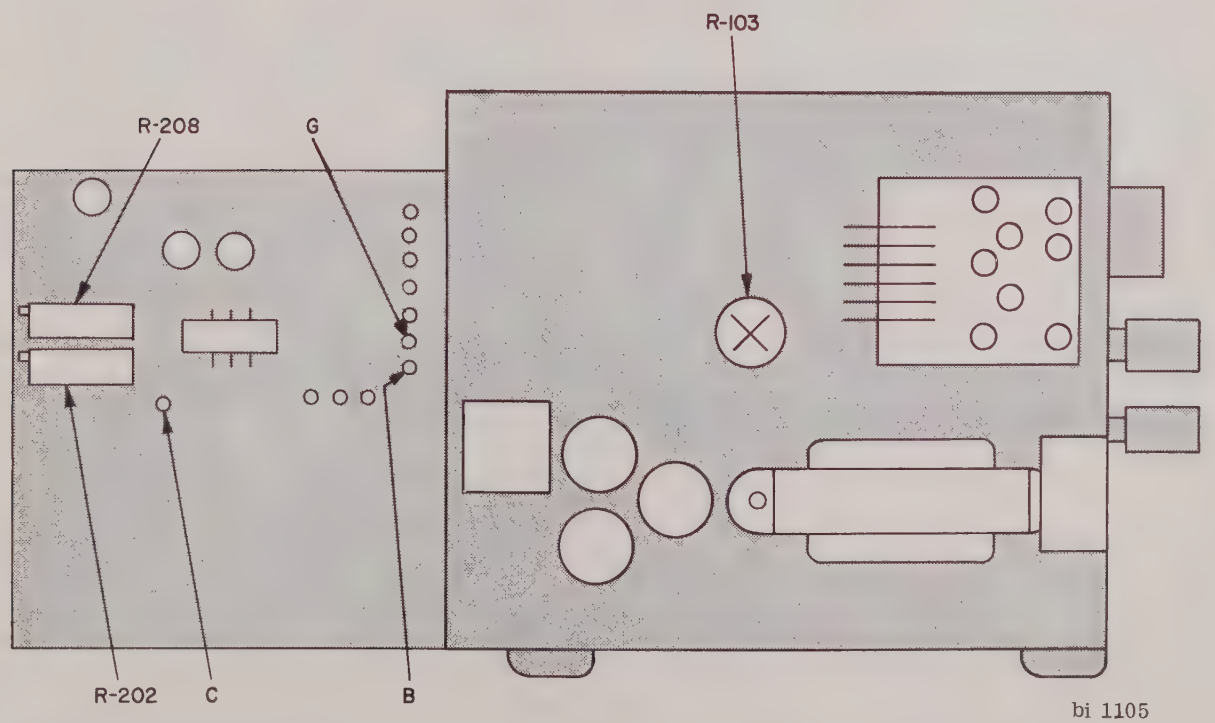


FIGURE 5-1 CALIBRATION TEST POINTS

6. With VOM measure voltage from point C to G (common). Voltage should be +14.4 volts ±20%.

7. With VOM measure voltage from point B to G (common). Voltage should be −14.4 volts ±20%.

8. Connect 100 ohm resistor across input terminals of differential voltmeter. Connect leads of differential voltmeter between pins 1 and 4 of signal input connector.

9. Adjust resistor, R-103, for +5 volts, ±5 mv d-c.

10. Connect oscilloscope between pins 1 and 4 (leave 100 ohm load connected). With HI cutoff of scope set to 1 kHz, noise should be less than 5 mv peak-to-peak.

11. Remove above test connections.

12. Short input pins 2 and 3 to common. Set CALIBRATE control to 2.0.

13. Connect differential voltmeter to amplifier output.

14. With SENSITIVITY control in OFF position, rotate POSITION control through its full range. Output should have a minimum swing of both plus and minus 2.9V d-c.

15. Set POSITION control for 0 volts d-c output within 20 mv.

16. Rotate SENSITIVITY control to 5% position and adjust resistor, R-208 for 0 volts d-c output within 150 mv.

17. Connect oscilloscope across output terminals. With HI cutoff of scope set for 1 kHz, noise must be less than 150 mv peak-to-peak.

18. With input pins 2 and 3 tied together connect a 10 volt peak-to-peak 100 Hz signal from pins 2 and 3 to common. Adjust resistor R-202 for minimum output (less than 500 millivolts) on oscilloscope.

19. Short input pin 2 to common and connect signal generator between pin 3 and common.

20. Set SENSITIVITY to 100% position.

21. Remove turns counting dial from unit and set it to read 2.00. Lock in this position.

22. Apply 3.5 mv RMS 100 Hz signal to input and adjust CALIBRATE control for 1.75 VRMS ±5 mv at the output.

23. Replace turns counting dial on CALIBRATE control.

24. Carefully replace amplifier board using five circuit board fasteners.

25. Replace side cover using four flat-head screws.

26. Unit is now ready for use.

5.4 MODIFICATION FOR 10VDC EXCITATION

The Brush D.C. Bridge Amplifier can quickly and easily be modified to provide 10 vd-c excitation voltage. To accomplish this modification, simply change fixed resistor R-104 from 5K ohms to 13.6K ohms. (13.6K ohm resistor part number is 25-265969-13601). Then repeat steps 8, 9, 10, and 11 of the calibration procedure, adjusting for 10 vd-c.

NOTE: In order to double transducer sensitivity (output), 10 volts may be used with transducers normally requiring only 5 volts excitation. However, users should beware that this increased excitation voltage may also cause unwanted transducer heating thereby producing signal drift.

SECTION VI

APPLICATIONS

6.1 AN INTRODUCTION TO STRAIN

Strain is a fundamental physical phenomenon. It exists in solids at all times, due either to loads or to the weight of the material itself. The terms "strain" and "physical deformation" are synonymous. In engineering strain refers to the change in any linear dimension of a body which is due to the application of either internal or external forces.

"Strain" as defined above refers to total strain, but we are primarily interested to "unit strain" which has much greater significance. Average unit strain is the total deformation of a body in a given direction divided by the original length in that direction. Unit strain as determined by a strain gage is expressed in microinches per inch.

$$\text{Strain} = \frac{\text{Change in Length}}{\text{Original Length}} \quad \text{(microinches)}$$

or

$$\varepsilon = \frac{\Delta L}{L}$$

The word "strain" (or "micro-strain") when used alone normally refers to "unit strain." Engineers and scientists have attempted for centuries to measure strain accurately, but only the last two decades has seen outstanding advancement in the art of strain measurement, made possible by the development of the bonded resistance strain gage.

6.2 WHY MEASURE STRAIN?

The measurement of strain can be beneficial to anyone in industry who is interested in developing or producing a superior product. During the past two decades strain measurement has opened up an entirely new branch of engineering called "experimental stress analysis." The strain gage has been used so extensively and so successfully in the aircraft industry that it can safely be said that without it aircraft performance and safety factors would be far below their high present day levels. Today, the bonded strain gage is finding its way into all heavy industries. From strain gage data, engineers can produce better machine designs which provide superior performance and reliability, weigh less and cost less to build. Strain gages are used in hundreds of industrial applications from strain analysis of smoke stacks to metal distortion in turbine blades, and from the flight of an arrow to the flight of an airliner. The only limit of strain gage applications appears to be the imagination of the user.

6.3 ACCURACY

Strain gages are electromechanical transducers that

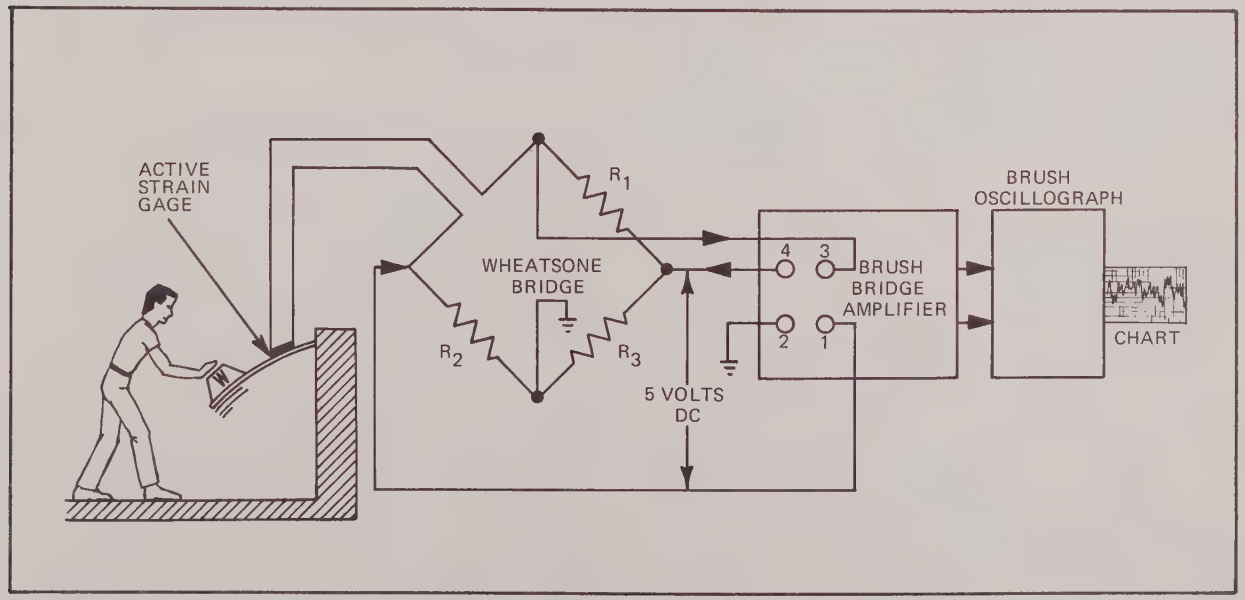


FIGURE 6-1 BASIC STRAIN RECORDING

are applied to the surface of the material. The strain gage exhibits a change of electrical resistance with a change in strain. The change is linear, and may be measured with suitable instrumentation. The method, although indirect, is precise. Accuracies of 1% are obtained with standard equipment, properly applied and operated with reasonable care. Accuracies up to 0.1% can be achieved by experts working with special apparatus. (Figure 6-1)

6.4 SENSITIVITY

Sensitivity of a strain gage is determined by the electrical conductivity of the sensing element material and its configuration. It is predetermined by the manufacturer. "Gage factor" is a measure of strain gage sensitivity. All commercial resistance strain gages have a positive gage factor. This means that an increase in strain produces an increase in strain gage resistance. Strain (ϵ) has been defined as the change in the length (ΔL) divided by the original length (L). The unit change in resistance that the strain produces is defined as the change in resistance (ΔR) divided by the original resistance (R).

Gage factor (G_f) is defined as the unit resistance change divided by the unit strain. That is:

$$G_f = \frac{\Delta R/R}{\Delta L/L}$$

The measured gage factor stated on each strain gage package should be used in all instrument calibrations.

6.5 AREA OF STRAIN MEASUREMENT

In use, each portion of the strain gage is intimately bonded to the member being tested and accurately follows its movements in both tension and compression. It measures the average of strains all along the gage length. If strain is localized in a small area, a short length gage must be used. Gages only 1/64" long are available for use when working space is limited.

For measuring large strains up to 10% elongation special "post yield" strain gages are available.

6.6 ROSETTES FOR COMPLEX STRAIN MEASUREMENTS

Single-element strain gages are designed to measure only those strains that are parallel to the strain gage axis. Transverse-axis sensitivity of a single-element gage is usually less than 2% of the normal "strain—axis" sensitivity and has negligible effect on output.

Where strain directions are not known, it is necessary to use multiple array strain gages called rosettes. The individual elements in a rosette gage are arranged to facilitate later calculation of both the magnitude and direction of the principal strains. Three separate channels are required to measure or record the strain data from a three-gage rosette.

The two most common types are the rectangular rosette which has gages oriented at 0°, 45° and 90° and the delta rosette with gages oriented at 0°, 60° and 120°. When the direction of principal strain is known approximately, the rectangular rosette is used so that the center gage can be oriented in the estimated direction of the principal strain. When the direction of the principal strain is completely unknown, the delta rosette should be used.

6.7 DURATION AND FREQUENCY OF STRAIN

Three general classes of strain work are encountered. The first is long-term measurement of static or slowly changing forces. This requires gages which provide consistent output under changing environmental conditions. The conventional strain gages used with proper temperature compensated strain gages, are both available for these long term, drift-free measurements.

The second class of strain work deals with rapidly varying strains of high magnitude. This work requires gage grid materials of high fatigue resistance. Isoelastic wire gages were developed specifically for this type of application, but they create difficult problems in temperature compensation.

The third class of strain work deals with a combination of static and dynamic strains plus transient temperature conditions. The new temperature-compensated foil gages are quite satisfactory for this class of work.

6.8 DESIRABLE CHARACTERISTICS OF STRAIN GAGES

An ideal universal strain gage would contain the following characteristics:

1. Ability to measure strains accurately under static or dynamic conditions.

2. Small size, light weight and negligible thickness.

3. Suitable for remote observation and recording.
4. Unaffected by temperature, vibration, humidity or other ambient conditions.
5. Easy to install on member being analyzed.
6. Good stability and negligible hysteresis.
7. Large linear output in response to strain.
8. Inexpensive.
9. Dependable and not subject to aging or fatigue.
10. Capable of operation as an individual strain gage or in multiple rosettes.

6.9 ETCHED FOIL STRAIN GAGES

Today the "etched foil" strain gage contains practically all of the foregoing features. Several hundred different types and sizes are commercially available from a number of sources. Bonded resistance strain gages are available today that will satisfy most engineering requirements.

Etched foil strain gages offer significant improvement over the earlier wire-grid gages in both electrical and mechanical performance, along with better application flexibility. Each grid element is many times wider than its thickness, providing a large bonding area. The end loops of the grid reduce transverse sensitivity of the gage and also reduce creep and hysteresis. Very thin gages are available in which the total thickness is less than 0.002 inches, allowing extreme flexibility and close contact to the mounting surface.

Etched foil gages have strain sensitivities from 5% to 20% greater than equivalent bonded wire strain gages.

a. Transverse Sensitivity

Etched foil gages are designed for minimum transverse strain sensitivity. Relatively low resistance in the loop ends, which join adjacent grid elements, results in very low transverse sensitivity factors of between 0.5% and 2.0%, providing greater accuracy in two-directional stress fields such as torque measurements.

b. Hysteresis and Strain Limits

Actual tests show the combined hysteresis and zero shift obtained with etched foil gages during strain reversals of ±1500 microinches per inch, to be less than 0.1% of the total strain excursion. Accurate strain measurements can be made up to 5% elongation with properly selected standard self-compensated foil strain gages. Special high elongation foil gages are available for large strains up to 15% elongation.

c. Fatigue Life

Many of the larger epoxy resin backed etched foil gages operated at a reversed cyclic strain level of ±1500 microinches per inch, will have a service life greater than 3,000,000 cycles. Increasing the strain level to ±2000 microinches per inch will reduce the strain gage life expectancy by a factor of 10 to 100, depending on environmental conditions.

d. Operating Temperatures

Etched foil gages are available which will operate from −320°F to +1200°F for static measurements or +1800°F for dynamic work. It is not practical to cover this entire range with a single gage.

e. Physical Construction and Versatility

Foil strain gages have a distinct advantage in their thin flat form which places the strain-sensitive grid close to the material under test and conforms accurately to surface contours. Flexible construction is achieved by using very thin fiberglass laminates and epoxy base carrier materials. These thin gages are excellent for contour fitting and fast curing applications for use at normal room temperature.

6.10 TEMPERATURE COMPENSATION

Temperature compensation is one of the most important and one of the most frequently over-looked factors in the field of strain measurement. It is possible to start out to measure strain and end up measuring ambient temperature changes. One large company had to scrap more than a million dollars worth of strain data because adequate temperature compensation was not achieved by conventional "dummy" gage compensating techniques. Any strain gage will respond to all strains in the test material whether the strains are thermally induced or produced by an external force or load. If you wish to record strain and not temperature changes, it is urged that you pay special attention to the temperature compensated bridge circuits, temperature compensated strain gages and temperature compensated lead wire systems which will be described later.

a. Self-Temperature-Compensated Gages

The terms ''self-compensated'', ''temperature-compensated'', or "self-temperature-compensated" are applied to strain gages intended for use on materials having a related thermal coefficient of expansion. The gage alloy is so processed that the combined effects of thermal coefficient of resistance in the gage and thermal coefficient of expansion in the mounting surface result in essentially zero resistance change due to temperature. This results in a very low value of "apparent" or "temperature-induced" strain.

When transient temperature conditions are encountered, best accuracy will be obtained by using temperature-compensated strain gages, available from several sources.

Self-temperature-compensated strain gages are designated by an extra letter and digit in their type number which indicate the expansion coefficient of the material for which the gage is designed. For example, C6 in the Budd Company type number, or S6 in a Baldwin type number, would indicate that the strain gage is designed for use on materials which have a thermal expansion of 6 parts per million per degree Fehrenheit (6 PPM/^{o}F).

b. Temperature Compensation in Lead Wires

Lead wire resistance and capacitance also change with temperature. Therefore, lead wires from strain gages to the amplifier must also be temperature compensated.

Many people make the mistake of connecting a single strain gage to the Wheatstone bridge with only two lead wires. Variation in ambient temperature introduces a variable resistance in one leg of the bridge, causing the measuring instrument to see a strain that is not there. Compensation for temperature variation in the leads can be provided by using the "Siemens" three-lead method shown in Figure 6-2. In this three-lead method, two of the leads are in adjacent legs of the bridge which cancels their resistance changes and does not disturb the bridge balance. The third lead is in series with the power supply and is, therefore, independent of bridge balance. The four-wire lead systems described in paragraph 6-11 are also temperature compensated.

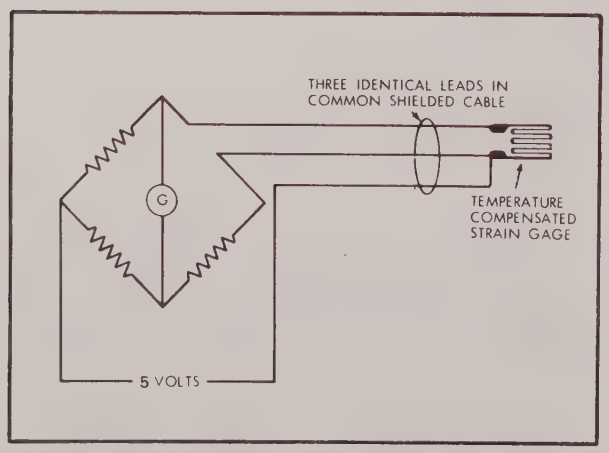


FIGURE 6-2 TEMPERATURE COMPENSATED THREE-LEAD WIRE SYSTEM

Each lead wire between the strain gages and the amplifier should be made exactly the same length and the same size of copper wire so that each lead wire will have exactly the same resistance. The three (or four) lead wires should be run in the same cable or laced snugly together so that all three are subjected to the same ambient temperature conditions. Changes in ambient temperature along the lead wire cable will not affect the strain measurements if the temperature is uniform at any cross-section along the cable. For long runs the size of the copper lead wires should be sufficiently large so that lead wire resistance is small when compared to the resistance of the Wheatstone bridge circuit. In strain gage work, never use the shield as a conductor.

6.11 LATERAL DEFORMATION (Figure 6-3)

Another possible source of errors in strain measurement is lateral deformation as produced by a given longitudinal deformation. In a specimen of uniform cross-section, this relationship is known as Poisson's Ratio.

By definition, Poisson's Ratio is the ratio of the transverse contraction per unit dimension in a bar of uniform cross-section to its elongation per unit length, when subjected to a tensile stress. When the material is subjected to compression, an equal and opposite effect takes place. For cold-rolled steel, for example, the Poisson's Ratio is 0.278; for various aluminum alloys it is 0.330 to 0.334. Poisson's Ratio must be taken into account whenever a temperature-compensating strain gage is mounted directly on the test specimen in simple tension or compression at right angles to the active strain gage. The single gage output will be increased directly in accordance to Poisson's Ratio for the material involved.

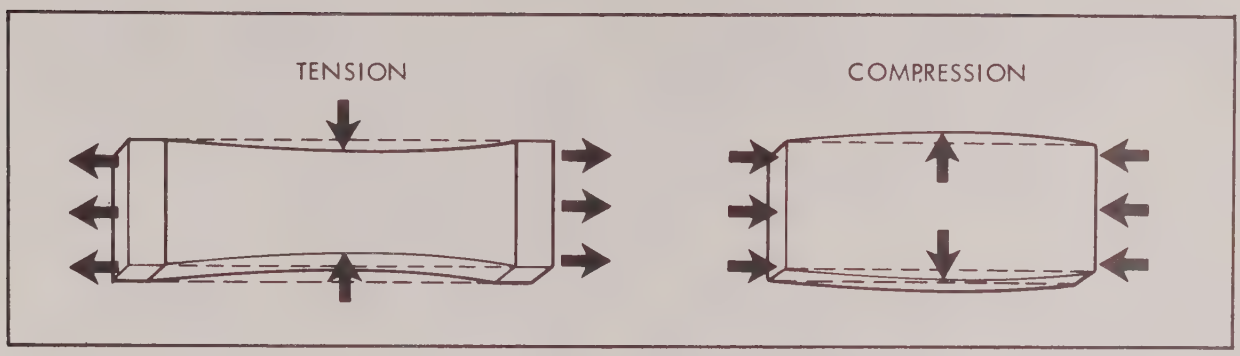


FIGURE 6-3 TYPICAL DEFORMATION OF A RECTANGULAR BAR UNDER TENSION AND COMPRESSION TESTS

6.12 BASIC STRAIN RECORDING CIRCUITS

The Wheatstone bridge circuit can be made up with one active strain gage and three fixed resistors, two active strain gages and two fixed resistors or four active strain gages. A basic Wheatstone bridge circuit is shown in Figure 6-4 with one active strain gage (R_g) and three fixed resistors (R_1,R_2, and R_3). Potentiometer (R_b) is used to balance the bridge with no load applied to active strain gage (R_g). Variable resistor (R_v) provides an adjustment of bridge excitation and thereby adjusts the bridge output.

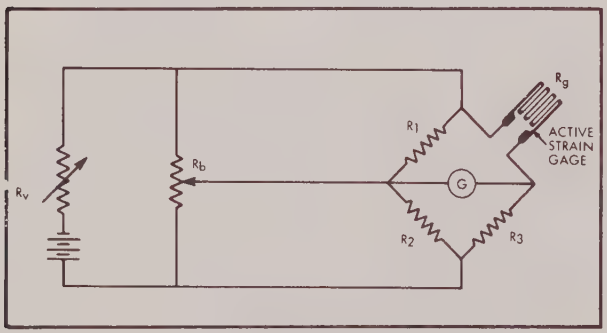


FIGURE 6-4 BASIC WHEATSTONE BRIDGE CIRCUIT

During normal strain measurements, the change in resistance (ΔR) of a resistance strain gage is so small in comparison to the unstressed resistance of the strain gage (R), that bridge linearity remains excellent. Bridge output can be considered directly proportional to changes in strain gage resistance as long as the strain gage receives constant current excitation.

When connecting the strain gages in a bridge circuit it is important to remember that the Wheatstone bridge output will be directly proportional to the difference of resistance changes in any two adjacent arms. Also, in any two opposite arms, the Wheatstone bridge output will be directly proportional to the sum of the resistance changes.

Until a few years ago, A.C. carrier frequencies were used almost exclusively for the excitation of passive type transducers because they worked much better than anything else that was available. Now solid-state electronics have permitted the development of appropriate D.C. amplifiers that have the necessary sensitivity, stability and noise rejection characteristics which makes them satisfactory for most applications.

D.C. Excitation Features

1. Frequency response is limited only by the characteristics of the amplifier selected.

2. Operating simplicity is achieved by elimination of reactive balance, phase adjustment and the balance/operate control.

3. Instrument versatility is improved since universal D.C. amplifiers are also used for many other applications.

4. Longer lead lengths can be used. Reactive transmission losses are eliminated.

5. Cross-talk interference with other circuits is minimized by eliminating the higher A.C. frequencies.

6. It is not necessary to synchronize adjacent D.C. amplifiers to eliminate "beating" because the higher carrier frequencies have been eliminated.

a. Assumed Circuit Conditions

Performance of the strain recording circuits illustrated on the following pages is based on these assumptions:

1. Constant current strain gage excitation, (I_C).
2. Minor changes in the modulus of elasticity (E) of the material due to temperature changes are neglected.
3. In Figures 6-10 and 6-11 transverse effects are neglected.
4. All the bridge circuits on the following pages receive excitation from the Brush Amplifier.

b. One Active Strain Gage

When one active strain gage is used, a Brush strain recording system is normally calibrated for a sensitivity of four microinch per inch of strain per chart division. The internal calibration system in most Brush strain amplifiers permits adjustment of amplifier gain so that this sensitivity may be obtained for any 100 to 1000 ohm strain gage with a gage factor of 2.0 or higher. If desired, the system may be calibrated for a lower sensitivity.

c. One Active Gage Without Temperature Compensation

The simplest but least accurate method of strain measurement employs only one active strain gage as shown in Figure 6-5. The inactive arms of the bridge circuit are completed with precision wire-would resistors or unstressed mounted gages of the same resistance value as the active gage.

With one active strain gage mounted and connected in a Wheatstone bridge circuit as indicated in Figure 6-5, the output of the bridge will be:

1. Proportional to the change in bending load, or...
2. Proportional to the change in axial load, or...
3. Proportional to the algebraic sum of the two above loads.
4. Also proportional to temperature changes.

Since this arrangement does not provide temperature compensation, it is not acceptable for accurate static measurements. It is useful only in the laboratory where temperature is closely controlled, for dynamic measurements where it is not necessary to measure static strain or where the static strain is of such short duration that temperature change effects are slight.

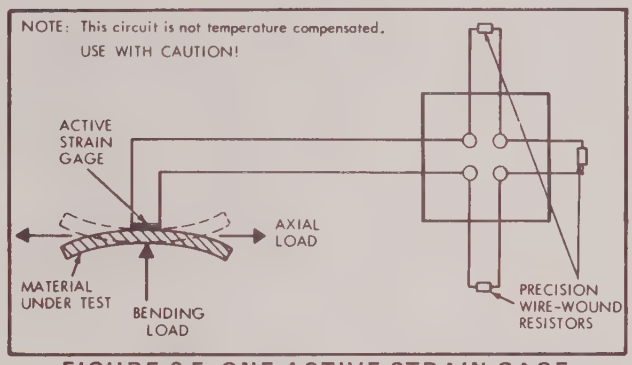


FIGURE 6-5 ONE ACTIVE STRAIN GAGE CONNECTED TO BRIDGE

d. One Active Temperature-Compensated Gage

One of the most popular techniques for securing temperature-compensation is to use a temperature-compensated strain gage which exhibits a very low temperature coefficient when mounted on the proper material. The bridge circuit, shown in Figure 6-6 should be completed with three unstressed, temperature-compensated gages mounted on the proper material. This arrangement performs well for both gradual changes in ambient temperature and transient temperature changes.

Temperature compensation in the lead wires is accomplished by using the "three-wire lead system" shown in Figure 6-6.

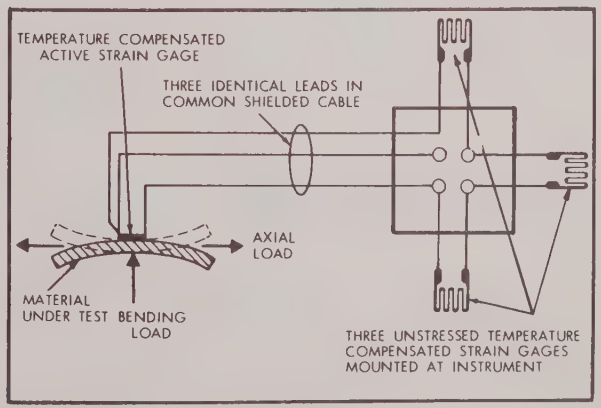

TEMPERATURE COMPENSATED ACTIVE STRAIN GAGE
THREE IDENTICAL LEADS IN COMMON SHIELDED CABLE
AXIAL LOAD
MATERIAL UNDER TEST
BENDING LOAD
THREE UNSTRESSED TEMPERATURE COMPENSATED STRAIN GAGES MOUNTED AT INSTRUMENT

FIGURE 6-6 STRAIN GAGE CONNECTED TO WITH THREE WIRE LEAD

With one temperature-compensated strain gage, mounted and connected in a Wheatstone bridge circuit as indicated in Figure 6-6, the output of the bridge will be:

1. Directly proportional to the change in bending load, or ...
2. Directly proportional to the change in axial load, or ...
3. Directly proportional to the algebraic sum of the two above loads.
4. Independent of temperature changes.

This arrangement is used only when axial loading remains constant during the measurement of bending loads or where bending load remains constant during the measurement of axial loads, or where the algebraic sum is desired.

e. One Active Gage and One Compensating Gage

One method to compensate for temperature changes in the material being tested is to apply a second strain gage to material of same composition, same head transfer characteristics and in the same temperature zone as material under test, but not subjected to strain. The temperature-compensating gage is connected in the bridge arm adjacent to the active strain gage.

Both the active gage and the compensating gage should be identical. This not only means identical resistance, gage factor, type and manufacturer, but from the same lot number of package and applied to the surface in exactly the same manner. The bridge should be completed with two identical precision wire-wound resistors or two identical unstressed gages mounted on a common plate or heat sink at the instrument.

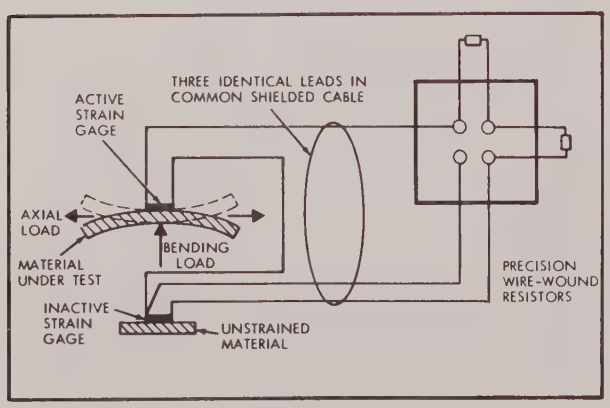


FIGURE 6-7 ONE ACTIVE AND ONE INACTIVE STRAIN GAGE CONNECTED

When one active strain gage and one temperature-compensating gage are mounted and connected in a Wheatstone bridge circuit as indicated in Figure 6-7, the output of the bridge will be:

1. Directly proportional to the change in bending load, or ...
2. Directly proportional to the change in axial load, or ...
3. Directly proportional to the algebraic sum of the two above loads.
4. Independent of temperature changes as long as these prevail uniformly at active and compensating gages.

This arrangement is subject to the same limitations as the previous circuit of Figure 6-6. Temperature compensation in the lead wires is achieved by running three identical leads in a common shielded cable.

f. Two Active Gages

Most Brush strain recording systems, using two active strain gages, can be calibrated to a sensitivity of two microinch per inch of strain per chart division, or twice that of a one-gage system.

g. In Adjacent Arms of the Bridge

An excellent strain recording circuit is achieved when two active strain gages are connected in adjacent arms of the bridge and subjected to strains of equal magnitude but of opposite sign. The bridge circuit is completed at the instrument with two identical precision wire-wound resistors or two identical unstressed gages mounted on a common plate or heat sink.

With two active strain gages mounted and connected in a Wheatstone bridge circuit as indicated in Figure 6-8, the output of the bridge will be:

1. Directly proportional to the change in bending load.
2. Independent of axial loads.
3. Independent of torsion.

4. Independent of temperature changes as long as these take place uniformly throughout the material.

5. Twice as large as the output from a single gage.

This arrangement is an easy method of achieving temperature compensation and determining the bending stresses in a member independent of axial thrust or tension. Temperature compensation in the lead wires is accomplished by using the three wire lead system.

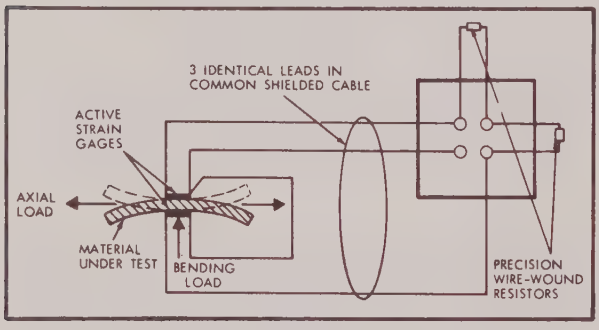


FIGURE 6-8 CONNECTING TENSION AND COMPRESSION STRAIN GAGES

h. In Opposite Arms of the Bridge

To obtain the sum of two separate strains install two active temperature-compensated gages and connect to opposite arms of the bridge. In this case temperature compensation in the lead wires is secured by using a separate three-wire lead system for each active gage.

i. Four Active Gages

Most Brush strain recording systems using four active strain gages can be calibrated to a sensitivity of one microinch per inch of strain per chart division, or four times that of a one-gage system. Satisfactory temperature compensation in the lead wires will be achieved by connecting all four strain gages to a terminal block in the vicinity of the gages, with identical jumpers. Then run four identical leads in a common shielded cable to the amplifier.

With four active strain gages mounted and connected in a Wheatstone bridge circuit as indicated in Figure 6-9, the output of the bridge will be:

1. Directly proportional to the change in bending load.

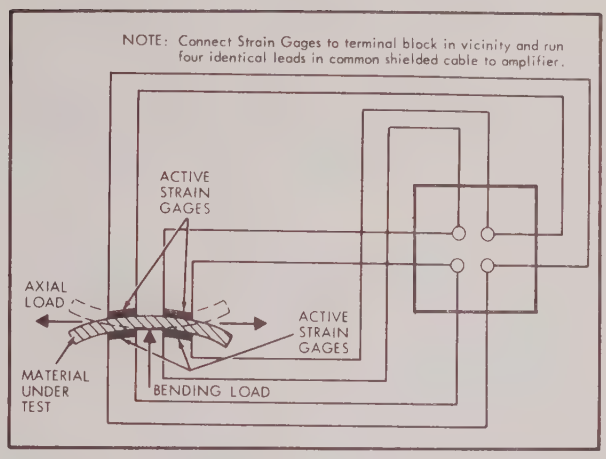

NOTE: Connect Strain Gages to terminal block in vicinity and run four identical leads in common shielded cable to amplifier.
ACTIVE STRAIN GAGES
AXIAL LOAD
ACTIVE STRAIN GAGES
MATERIAL UNDER TEST
BENDING LOAD

FIGURE 6-9 CONNECTING TWO TENSION AND TWO COMPRESSION STRAIN GAGES

2. Independent of axial loads.

3. Independent of torsion.

4. Independent of temperature changes as long as these take place uniformly throughout the material.

5. Four times as large as the output from a single gage.

This arrangement is often used for the following reasons:

1. Temperature compensation is achieved without difficulty.

2. Bending stresses can be measured independent of axial thrust or tension.

3. The bridge circuit produces maximum output.

j. Two Active Gages and Two Compensating Gages

This Poisson's (P_r) arrangement of strain gages is frequently used to measure strain produced by axial thrust, load or tension by mounting four gages directly on the material under test. Two active gages are mounted parallel to the center line (axial) but on opposite sides of the member. The two temperature compensating gages are moutned at right angles to the two active gages. As shown in Figure 6-10, the two active gages are connected in opposite arms of the bridge to add their output and each of the other gages is connected adjacent to an active gage which not only provides temperature compensation, but increases the bridge output in accordance with Poisson's Ratio (P_r) for the material involved.

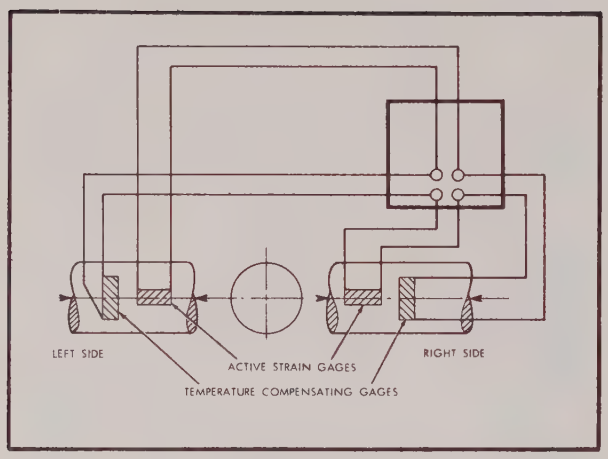


FIGURE 6-10 CONNECTING STRAIN AND COMPENSATING GAGES TO MEASURE THRUST, LOAD OR TENSION

When the four gages are mounted on a member of uniform cross-section and connected in the four arms of a Wheatstone bridge as indicated in Figure 6-10, the output of the bridge, for a change in axial thrust, load or tension will be:

1. Directly proportional to the change in applied load.
2. Independent of bending.
3. Independent of temperature changes as long as these take place uniformly throughout the material.
4. Independent of torsion.
5. $2(1 + P_r)^* = 2(1 + 0.287) = 2.574$ times as large as the output from a single gage.

***(P_r) Poisson's Ratio is discussed in paragraph 6.11, Lateral Deformation. Poisson's Ratio (P_r) for cold rolled steel is 0.287.**

Temperature compensation in the lead wires is achieved by connecting strain gages to an adjacent terminal block with identical leads and running a shielded cable containing four identical color coded leads from the terminal block to the amplifier. This arrangement is frequently used in applications where the principal strain occurs in only one direction.

k. Four Active Gages for Recording Torque

When a cylindrical shaft is subject to torsion, the principal axes of strain on the surface will be inclined at 45° to the axis and the magnitude of these strains will be equal but in opposite directions.

Measurement of torsion or torque can be accomplished quite easily by mounting two active gages on a shaft at right angles to one another and oriented as indicated in Figure 6-11. Under these conditions, one gage is in tension while the other gage is in compression so they are connected in adjacent arms of the bridge. A similar pair of active gages is installed on the opposite side of the specimen from the first pair in order to double the bridge output and provide a measurement which is independent of bending.

When the four strain gages are mounted on the shaft and connected in a Wheatstone bridge circuit as indicated in Figure 6-11, the output of the bridge will be:

1. Directly proportional to the applied torque.
2. Independent of bending.
3. Independent of temperature changes as long as these take place uniformly throughout the shaft.
4. Independent of axial loading.

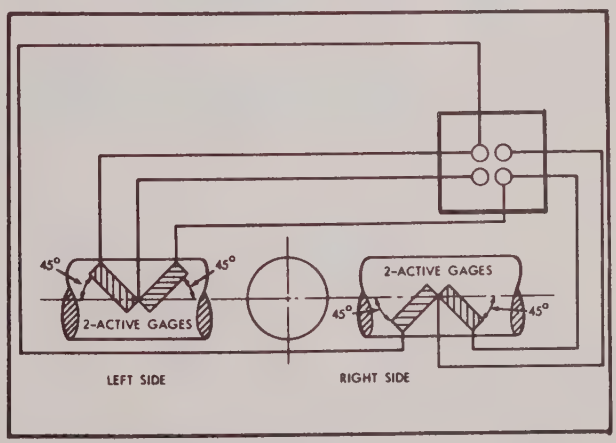


FIGURE 6-11 CONNECTING STRAIN GAGES TO MEASURE TORQUE

5. Four times as large as the output from a single strain gage.

Temperature compensation in the lead wires is achieved by connecting strain gages to an adjacent terminal block with identical leads and running a shielded cable containing four identical color coded leads from terminal block to amplifier.

The output from the bridge circuit may be taken off a rotating shaft by appropriate slip rings. Both the slip rings and brushes must be of high quality and in good state of repair so that variable resistances are not introduced into the circuit. Torque can also be measured with two active strain gages mounted at right angles to each other and connected to adjacent arms of the bridge. This is NOT independent of bending and has half the output of the previous circuit. Temperature compensation in lead wires is automatically accomplished by using the conventional three-wire lead system.

6.13 ELIMINATION OF ERRORS IN WHEATSTONE BRIDGE CIRCUITS

a. Avoiding Variable Contact Resistance and Thermocouple Effects

All connections in the Wheatstone bridge circuit must be low resistance joints in order to secure accurate recordings. Difficulties from contact resistance can be avoided by soldering, fusing, welding or by using good compression type connectors. The usual "banana plug" type of connector must be avoided, but a tight screw-down connection on clean, tinned copper wire is quite acceptable. For d-c excited bridge circuits thermocouple effects can be minimized by placing both strain gage lead wire junctions close together physically, in the same temperature zone and encasing them with cement on a common piece of metal or other form of "heat-sink."

b. Provide Adequate Lead Wire Support

If strain gage leads are allowed to hang freely from great heights, the strains produced in the leads, by their own weight, will change the lead wire resistance and cause strain measurements to vary. The movement of leads can also cause capacity changes in the lead wires, which will produce a capacity unbalance in the bridge circuit. A good example of this is where lead wires are allowed to flop against a metallic column or pipe or are allowed to hang loosely in a large vertical conduit. It is most desirable to lace a lead together in a single cable and tie down the cable firmly so that the strain gage readings are not modulated by the swinging of the lead wires.

6.14 RECORDING FROM STRAIN GAGE BASED TRANSDUCERS

The great versatility of the strain gage has now been realized through its use as the heart of the precision bridge type sensing elements employed in many pre-packaged transducers.

a. Commercially Available Types

Typical of the many transducers now available are the various types of load cells, pressure gages, torque meters, accelerometers, flow meters, and load beams. Each is precision built and calibrated to handle a large range of variables encountered in scientific, military and industrial fields. These not only include complex applications like measuring the flow of fuel to rocket engines and recording its torque or acceleration against time, but common every-day tasks such as automatically weighing packages of sugar or regulating the coal feed in an electric power plant.

b. Use Either Bonded or Unbonded Type Transducers

There are two basic types of strain gage based transducers which are widely used. These are the bonded type and the unbonded type. The bonded type gage usually takes the form of a flat grid which is cemented directly to the sening element. Four strain gages, connected in a conventional Wheatstone bridge are generally used for the sensing circuit. Temperature compensation, linearity, hysteresis and moisture resistance all receive special consideration during the design and manufacture of the transducer.

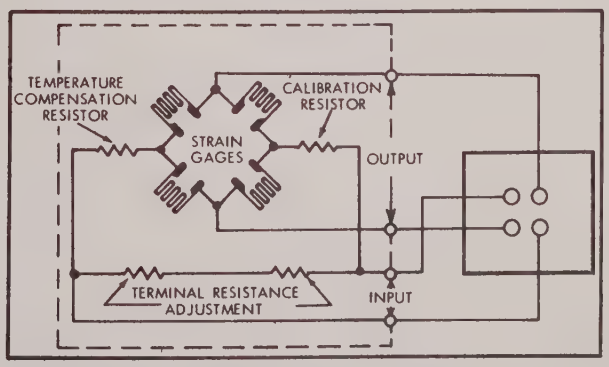


FIGURE 6-12 CONNECTING TYPICAL LOAD CELL

The unbonded strain gage consists of a stationary frame which supports a moveable armature through thin cantilever plates. The strain-sensitive wire is strung under tension between pins located on the frame of the transducer and pins located on the moveable armature.

Four filaments are normally used in each transducer, connected in a conventional Wheatstone bridge, which makes up the sensing circuit. As the armature is moved longitudinally by an external force, the resistance increases in one pair of filaments and decreases in the other. This provides a bridge output that is directly proportional to the longitudinal movement or the force applied. The choice between bonded or unbonded strain gage based transducers depends on the specific application and the personal preference of the user.

Brush Bridge Amplifiers can be used with strain gage based transducers with resistance values from 100 to 1000 ohms. These amplifiers can be used with almost any of the commercially available strain gage based transducers. Most of these devices contain four active gages and may be connected to the Bridge Amplifier in exactly the same manner as shown for the Typical Load Cell in Figure 6-12. Four identical (low resistance) leads in a common shielded cable will provide adequate lead wire temperature compensation. Strain gage based transducers having less than four active gages may also be used by following the appropriate procedure outlined in the use of individual strain gages.

SECTION VII

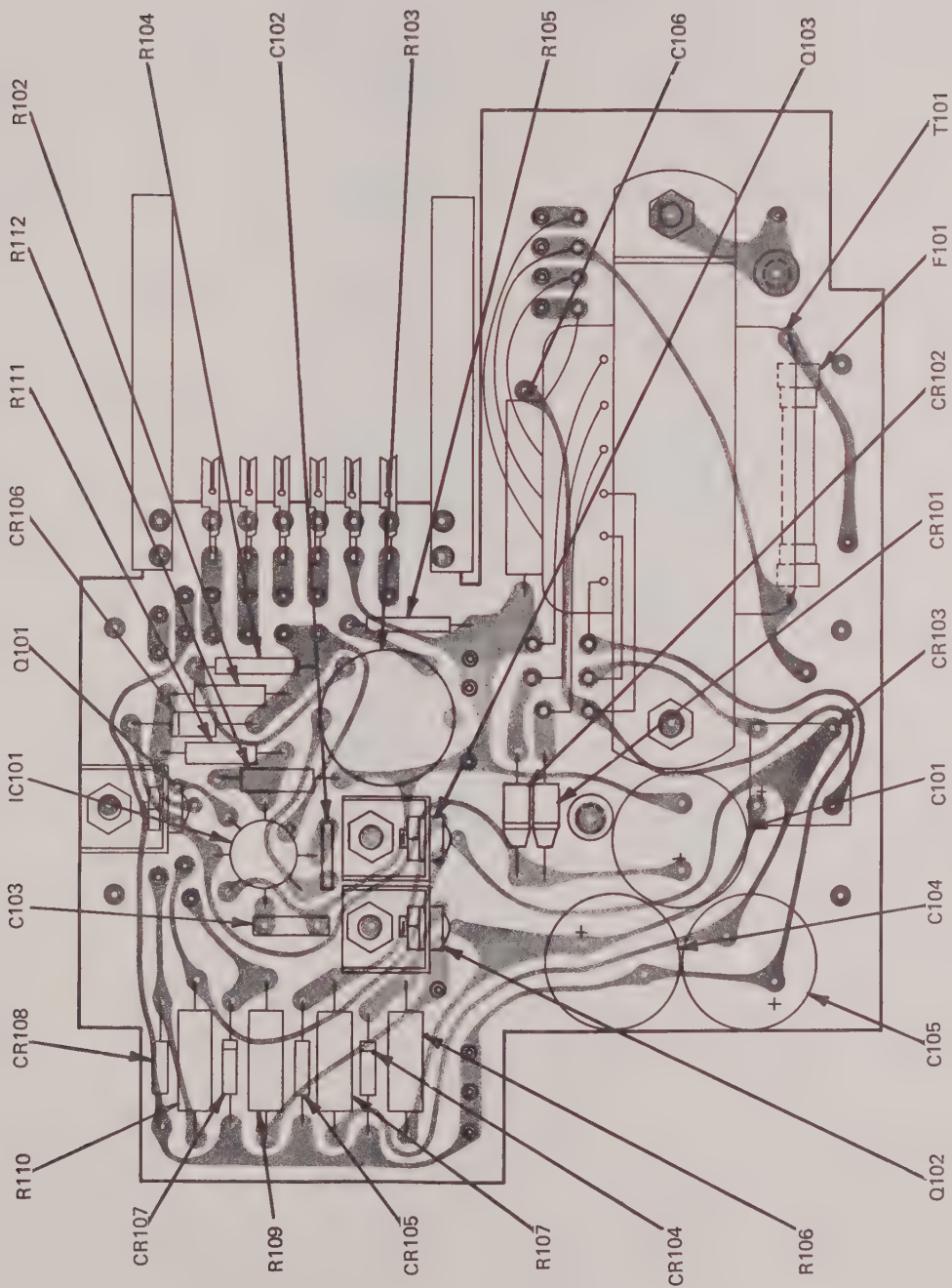
PARTS IDENTIFICATION

ELECTRICAL PARTS LIST
D.C. BRIDGE AMPLIFIER
MODEL 13-4312-00

SYMBOL NO	PART NUMBER	DESCRIPTION
C-301	240352-103	Capacitor
J-302	126395-2	Jack
J-303	126395-13	Jack
J-304	126395-3	Jack
P-301	244810	Connector
P-302	247364	Connector
R-301	230064-103	Resistor, Variable
R-302	230050-103	Resistor, Variable
R-303	230065-251	Resistor, Variable
R-304	50-128182-1001	Resistor
R-305	50-128182-5000	Resistor
R-306	50-128182-3000	Resistor
R-307	50-128182-1000	Resistor
R-308	50-128182-1000	Resistor
S-301	268647	Switch
S-302	247185	Switch

ELECTRICAL PARTS LIST
D.C. BRIDGE AMPLIFIER, MODEL 13-4312-00
POWER SUPPLY BOARD ASM 868638

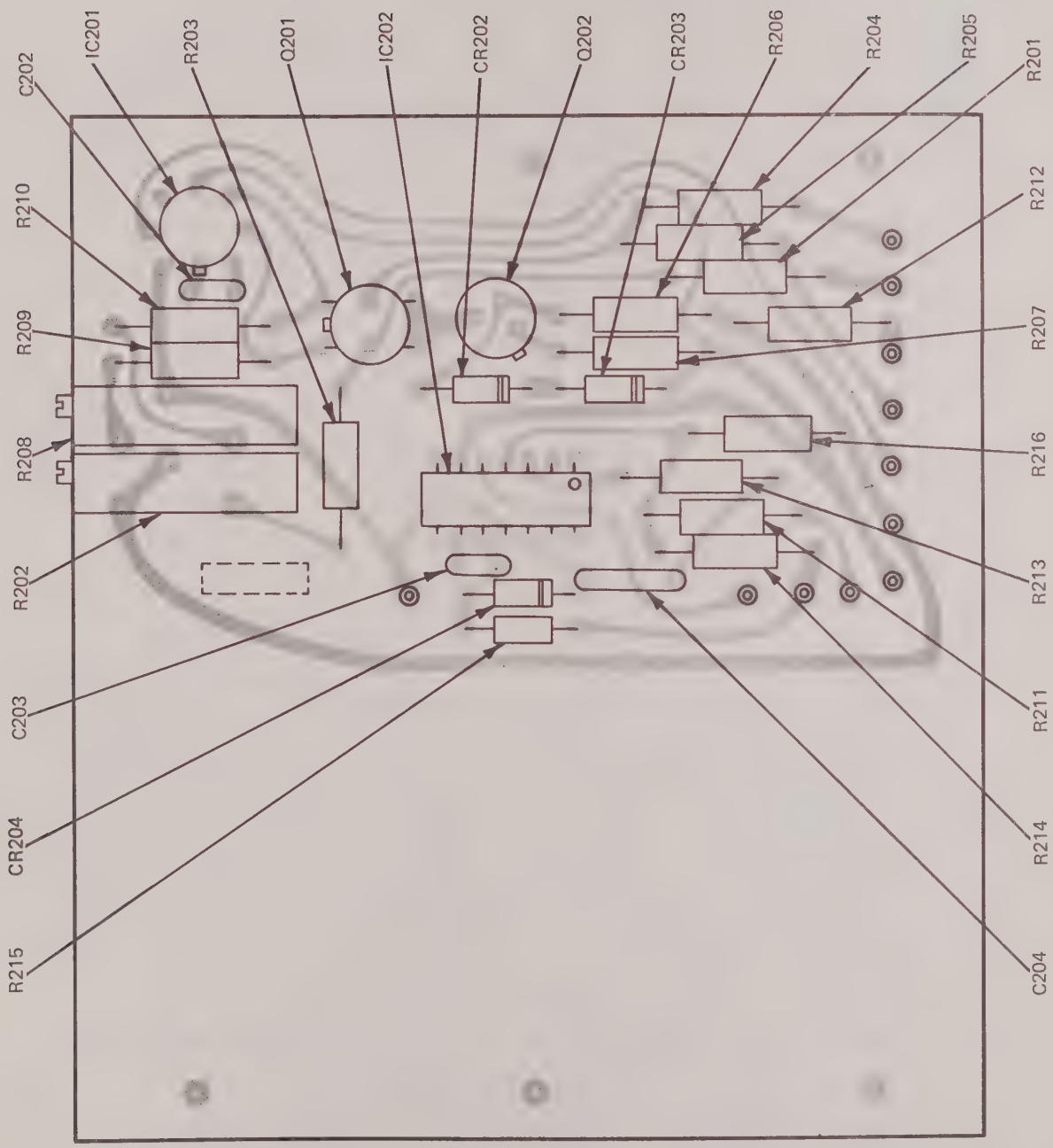
SYMBOL NO	PART NUMBER	DESCRIPTION
C-101	230075-507	Capacitor
C-102	240352-560	Capacitor
C-103	20-247195-203	Capacitor
C-104	230075-507	Capacitor
C-105	230075-507	Capacitor
C-106	241164-505	Capacitor
CR-101	130198-1	Diode, 1N2069
CR-102	130198-1	Diode, 1N2069
CR-103	265420-1	Diode Bridge
CR-104	230061-2	Diode, Zener 1N4744A
CR-105	230061-2	Diode, Zener 1N4744A
CR-106	231887	Diode
CR-107	246107	Diode, Zener, 1N746
CR-108	246107	Diode, Zener, 1N746
F-101	264798-3	Fuse, 3AG, 1/8 amp
IC-101	230046	Integrated Circuit
Q-101	230058-1	Transistor, 2N4918
Q-102	240057-1	Transistor, 2N4921
Q-103	230058-1	Transistor, 2N4918
R-102	5-115557-4R7	Resistor
R-103	248813-102	Resistor, Variable
R-104	50-128182-5001	Resistor
R-105	50-128182-2501	Resistor
R-106	5-115558-561	Resistor
R-107	5-115558-561	Resistor
R-109	5-115558-241	Resistor
R-110	5-115558-241	Resistor
R-111	5-115557-470	Resistor
R-112	5-115557-102	Resistor
T-101	267952	Transformer



D.C. BRIDGE AMPLIFIER, MODEL 13-4312-00
POWER SUPPLY BOARD ASM 868638

ELECTRICAL PARTS LIST
D.C. BRIDGE AMPLIFIER, MODEL 13-4312-00
AMPLIFIER BOARD ASM 868730

SYMBOL NO	PART NUMBER	DESCRIPTION
C-202	240352-201	Capacitor
C-203	240352-201	Capacitor
C-204	240352-502	Capacitor
CR-202	231869	Diode, 1N816
CR-203	231869	Diode, 1N816
CR-204	231887	Diode
IC-201	230062	Integrated Circuit
IC-202	230064	Integrated Circuit
Q-201	268929	Transistor, 2N4044
Q-202	245752	Transistor, 2N1711
R-201	25-265969-25001	Resistor
R-202	268940-104	Resistor, Variable
R-203	25-240368-12003	Resistor
R-204	25-265969-25001	Resistor
R-205	25-240368-12503	Resistor
R-206	5-115557-822	Resistor
R-207	1-128182-3502	Resistor
R-208	268940-104	Resistor, Variable
R-209	25-240368-50002	Resistor
R-210	25-240368-50002	Resistor
R-211	25-265969-50001	Resistor
R-212	50-128182-5000	Resistor
R-213	5-115557-152	Resistor
R-214	25-265969-50001	Resistor
R-215	5-241111-202	Resistor
R-216	25-240368-13850	Resistor



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AMPLIFIER BOARD ASM 868730

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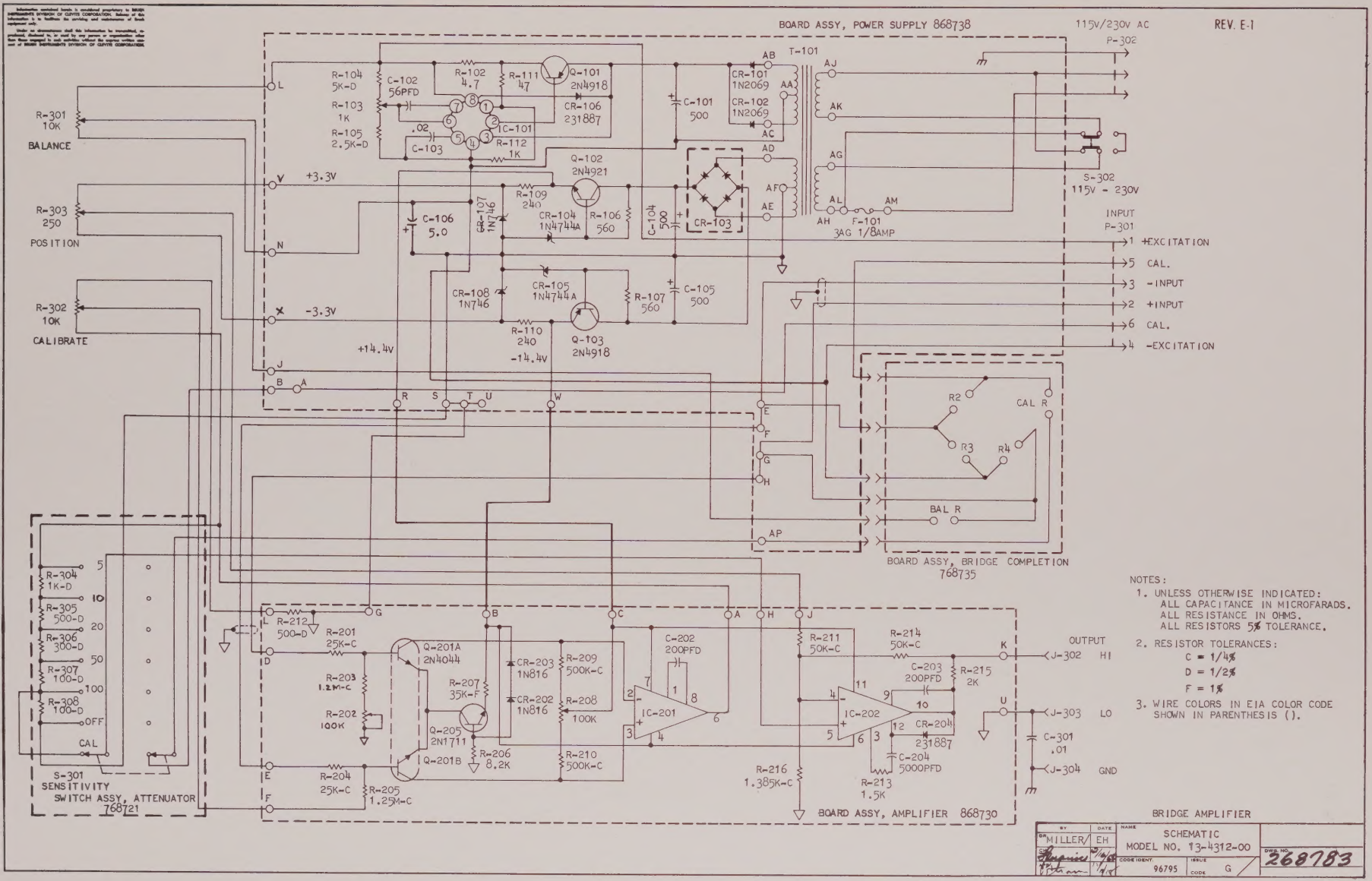

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